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(71) 出願人 000003713

大同特殊鋼株式会社

愛知県名古屋市中区錦一丁目11番18号

(72) 発明者 冷水 孝夫

愛知県名古屋市中白区表山二丁目311番地

八事サンハイツ501

(72) 発明者 堀尾 浩次

愛知県東海市加木屋町南鹿持18 大同特殊

鋼知多寮C-317

(72) 発明者 鬼頭 一成

愛知県名古屋市中緑区古鳴海二丁目38番地

(74) 代理人 100095669

弁理士 上野 登 (外1名)

最終頁に続く

(54) 【発明の名称】 拡管用金属管接合体及びその製造方法

(57) 【要約】

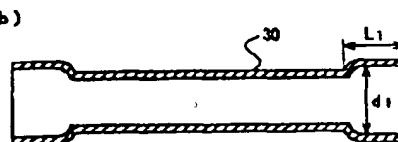
【課題】 拡管した場合であっても、接合部の強度及び気密性が低下することがなく、また、拡管する際の変形抵抗が少なく、しかも、接合部に発生する段差を小さくすることができる拡管用金属管接合体及びその製造方法を提供すること。

【解決手段】 端部拡径率が5%以上となるように端部近傍の内径が拡径された金属管30同士を拡散接合又は溶接し、あるいは端部近傍の内径が拡径されていない金属管50を所定の横断出率となるように拡散接合することにより、接合部の内径が非接合部の内径より大きくなっている金属管接合体32、52を得る。また、端部拡径率が10%以上となるように端部近傍の内径が拡径された金属管40同士を機械的に締結することにより、接合部の内径が非接合部の内径より大きくなっている金属管接合体42を得る。

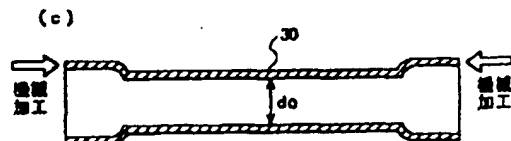
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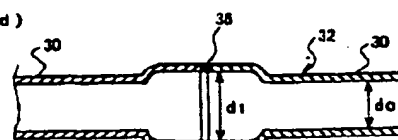
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(c)



(d)



## 【特許請求の範囲】

【請求項1】 複数の金属管が接合された金属管接合体であって、接合部の内径が、非接合部の内径より大きいことを特徴とする拡張用金属管接合体。

【請求項2】 金属管の端部近傍の内径を拡張し、該金属管同士を接合することを特徴とする拡張用金属管接合体の製造方法。

【請求項3】 端部拡張率が5%以上となるように、前記金属管の端部近傍の内径を拡張することを特徴とする請求項2に記載の拡張用金属管接合体の製造方法。

【請求項4】 接合方法が拡散接合法であることを特徴とする請求項2又は3に記載の拡張用金属管接合体の製造方法。

【請求項5】 接合方法がアーク溶接法であることを特徴とする請求項2又は3に記載の拡張用金属管接合体の製造方法。

【請求項6】 金属管の端部近傍の内径を拡張し、該金属管の端部にねじを形成し、該ねじにより前記金属管同士を機械的に締結することを特徴とする拡張用金属管接合体の製造方法。

【請求項7】 端部拡張率が10%以上となるように、前記金属管の端部近傍の内径を拡張することを特徴とする請求項6に記載の拡張用金属管接合体の製造方法。

【請求項8】 端部近傍の内径が拡張されていない金属管を突き合わせ、接合部近傍が横膨出するような接合条件で拡散接合することを特徴とする拡張用金属管接合体の製造方法。

【請求項9】 接合部近傍の横膨出率が1.04以上となるように拡散接合することを特徴とする請求項8に記載の拡張用金属管接合体。

## 【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、拡張用金属管接合体及びその製造方法に関し、更に詳しくは、化学工業、石油化学工業等で用いられるプラント用配管、ラインパイプ、あるいは油井で用いられるケーシングチューブ、生産チューブ、コイルドチューブ等の油井管として好適な拡張用金属管接合体及びその製造方法に関するものである。

【0002】

【従来の技術】従来から、化学工業、石油化学工業等の分野においては、腐食性の流体を長距離に亘って輸送するために、長尺の金属管が使用されている。例えば、パイプラインは、油田から得られた原油等を精油所等に輸送するためのものであり、その長さは数十kmに及ぶ。

【0003】また、油井を掘削するに際しては、地中に掘削された坑道の保護や原油の漏出防止等のために、坑道の中にケーシングと呼ばれる鋼管が埋設される。油田は、通常、地下数千mの位置にあるので、ケーシングも数千mの長さを有するものが必要とされる。

【0004】一方、腐食環境に曝される金属管には、耐食性に優れた継目無鋼管が一般に用いられるが、工業的に量産されている継目無鋼管の長さは、10~15mであり、製造可能な長さの上限は100m程度である。従って、ラインパイプ、あるいはケーシング等の油井管には、長さ10~15mの継目無鋼管を複数個接続した接合体が用いられている。

【0005】このような用途に用いられる金属管の接合方法としては、ねじ接続法（メカニカルカップリング法）、溶接法（オービタルウェルディング法）、拡散接合法などが知られている。

【0006】また、所定の長さを有する金属管が複数個接合された接合体（以下、これを「金属管接合体」という）は、内径を拡大あるいは縮小させることなくそのまま使用されるのが一般的である。すなわち、所望の内径を有する金属管接合体は、所望の内径を有する金属管を接合することにより製造されるのが一般的である。

【0007】しかしながら、地上に敷設されるラインパイプ等と異なり、油井に用いられるケーシング等は、地中に埋設されるものであるため、所望の内径を有する金属管接合体をそのままケーシング等として使用すると以下のような問題がある。

【0008】すなわち、地下数千mの位置にある油田に向かって裸坑のまま坑道を掘り進むのは困難である。そのため、油井の掘削作業は、先端にビットが取り付けられたドリルパイプを用いて坑道を掘削する作業と、ある程度掘り進んだところで、坑道を保護するためにケーシングを埋設する作業と、埋設されたケーシングと地層の間にセメントを流し込み、ケーシングを固定する作業とが順次繰り返される。その結果、油井は、複数のケーシングが入れ子状に重なった構造となる。

【0009】図6に油井の一般的な構造を示す。図6に例示する油井10は、地表付近の坑壁を保護するための最大外径を有するコンダクターパイプ12と、コンダクターパイプ12の中に順次入れ子状に挿入される、サーフェスケーシング14、中間ケーシング16、及び油層20まで達する最長の生産ケーシング18の4つのケーシングを備えている。

【0010】しかしながら、先に埋設されたケーシング（以下、これを「外側ケーシング」という）の中央の穴を通して、次のケーシング（以下、これを「内側ケーシング」という）を坑道内に埋設する際、内側ケーシングと外側ケーシングの軸がずれていたり、あるいは内側ケーシング又は外側ケーシングのいずれか一方の形状が不規則になっていると、内側ケーシングの挿入が困難になる場合がある。そのため、内側ケーシングの外径は、余裕を見込んで、外側ケーシングの内径より10~30%程度小さくする必要があった。

【0011】また、油井の生産能率は、油層に達する生産ケーシングの内径に依存する。従って、所定の生産能

率を確保するためには、生産ケーシングの内径を所定の大きさとするのみならず、先に埋設されるケーシングの内径も大きくする必要がある。そのため、地表付近に掘削される坑道の内径を大きくする必要が生じ、油井掘削コストを増大させる原因となっていた。

【0012】そこで、この問題を解決するために、特表平7-507610号公報には、地中に掘削されたボアホールに可鍛材料製ケーシングを埋設し、液圧膨張ツールをケーシング内で膨張させることにより、ケーシングをボアホール壁に対して半径方向に膨張させる方法が開示されている。

【0013】また、特許協力条約に基づく国際公開第WO98/0062号には、ネッキングや延性破壊することなく歪硬化を生ずる可鍛性の鋼種からなる鋼管を坑道、あるいは先に埋設されたケーシング内に挿入し、非金属材料からなるテーパ面を有するマンドレルを用いてケーシングを拡張する方法が開示されている。

【0014】特表平7-507610号公報あるいは国際公開第WO98/0062号に開示された方法によれば、坑道あるいは外側ケーシングの内径に比して、相対的に小さな外径を有する内側ケーシングを挿入することができるので、内側ケーシングの挿入作業を円滑に行うことができるという利点がある。

【0015】また、液圧膨張ツール又はマンドレルを用いて、坑道あるいは外側ケーシングに挿入された内側ケーシングの拡張が行われるので、坑道の断面積のほぼ全部を原油輸送に使用できるという利点がある。また、坑道の有効断面積が大きくなることにより、掘削すべき坑道の内径を小さくすることができ、掘削コストを削減できるという利点がある。

【0016】さらに、特表平7-507610号公報に開示されているように、ケーシングをボアホール壁に対して半径方向に膨張させた場合には、ボアホール壁から受ける圧縮応力によりケーシングが保持されるので、セメンティング作業が不要になるという利点がある。

【0017】

【発明が解決しようとする課題】しかしながら、油井に用いられるケーシングは、全長が数千mに達するものであり、接合部が必ず存在するにもかかわらず、特表平7-507610号公報あるいは国際公開第WO98/0062号に開示されている方法においては、接合部が全く考慮されていない。

【0018】例えば、金属管を溶接法、あるいは拡散接合法等の冶金接合法により接合して金属管接合体とした場合には、接合部近傍は、接合時の加熱により熱影響部が発生し、変形能が低下していることがある。そのため、得られた金属管接合体をそのままマンドレル等を用いて拡張した場合には、接合部に亀裂が発生するおそれがあるという問題がある。

【0019】また、例えば、金属管をねじ接続法により

接合して金属管接合体とし、これをマンドレル等を用いて拡張した場合には、拡張時の塑性変形によってねじの部分で弛み、接合部の気密性が低下するという問題がある。

【0020】さらに、ねじ接続法は、図7に示すように、通常、金属管1、2の端部に外ねじ1a、2bを形成し、その外ねじ1a、2bと螺合可能な内ねじ7aを有する継手7を介して、金属管1、2が接合される。従って、接合部近傍は、非接合部に比して厚肉となるので、このような金属管接合体をマンドレル等を用いて拡張した場合には、接合部の変形抵抗が大きくなり、拡張作業を円滑に行うことができないという問題がある。

【0021】また、マンドレルを用いて、同一内径を有する長さ数千mの金属管接合体を一気に拡張する場合、マンドレルは、拡張時に金属管接合体から絶えず反力を受け続けるので、マンドレルを移動させるのに大きな動力が必要となる。

【0022】この問題を解決するために、例えば、国際公開第WO98/0062号には、マンドレルのテーパ面をジルコニア等の非金属材料で構成することにより、マンドレルとケーシング間に発生する摩擦力を低減する点が開示されているが、拡張中にマンドレルが絶えずケーシングから一定の反力を受け続ける点に変わりはなく、省動力化という点では不十分である。

【0023】一方、特表平7-507610号公報に開示されているように、液圧膨張ツールをケーシング内のある位置に保持し、液圧膨張ツールを膨張させてその位置にあるケーシングのみを拡張し、次いで液圧膨張ツールを収縮させた後に上方に移動させるというプロセスを繰り返せば、マンドレルを用いて一気に拡張する場合に比して省動力化することができる。しかしながら、ケーシングを段階的に拡張することになるので作業能率が低いという欠点がある。

【0024】さらに、拡散接合法を用いて金属管を接合する場合、金属管は、端面のみを平坦に加工し、外周面及び肉厚の修正をすることなく、そのまま接合に用いるのが一般的である。一方、工業的に量産される金属管には、所定の寸法公差があり、各金属管の外径及び肉厚は、寸法公差の範囲内でばらついている。

【0025】そのため、量産された金属管をそのまま用いて拡散接合した場合には、得られる金属管接合体の接合部に段差が発生するおそれがある。接合部に発生した段差には、応力が集中しやすいので、このような金属管接合体を拡張した場合には、段差部分から亀裂が発生するおそれがある。また、拡張後も接合部に段差が残るために、応力集中や、段差部分に腐食性物質が滞留することに起因して、強度、疲労特性及び耐食性が低下するおそれがある。しかしながら、このような問題を解決する具体的手段についても、上述した先行技術文献には、何ら開示されていない。

【0026】本発明が解決しようとする課題は、拡張を行っても接合部に亀裂が発生したり、ねじの緩みに起因する接合部の気密性の低下が生ずることのない拡張用金属管接合体及びその製造方法を提供することにある。

【0027】また、本発明が解決しようとする他の課題は、拡張する際の变形抵抗が小さく、しかも拡張作業の省動力化が可能な拡張用金属管接合体及びその製造方法を提供することにある。

【0028】さらに、本発明が解決しようとする他の課題は、接合部に発生する段差が小さく、しかも強度、疲労特性及び耐食性に優れた拡張用金属管接合体及びその製造方法を提供することにある。

【0029】

【課題を解決するための手段】上記課題を解決するために、本発明に係る拡張用金属管接合体は、複数の金属管が接合された金属管接合体であって、接合部の内径が、非接合部の内径より大きいことを要旨とするものである。

【0030】このような拡張用金属管接合体は、具体的には、予め金属管の端部近傍の内径を拡張し、該金属管同士を接合することにより容易に製造することができる。この場合、端部拡張率が5%以上となるように、前記金属管の端部近傍の内径を拡張することが望ましい。端部拡張率が5%未満になると、拡張を行う際に、接合部から亀裂が発生するおそれがあるので好ましくない。また、この場合、接合方法としては、拡散接合法又はアーク溶接法が好適である。

【0031】また、上述のような拡張用金属管接合体は、金属管の端部近傍の内径を拡張し、該金属管の端部にねじを形成し、該ねじにより前記金属管同士を機械的に締結することによっても製造することができる。この場合、端部拡張率が10%以上となるように、前記金属管の端部近傍の内径を拡張することが望ましい。端部拡張率が10%未満になると、拡張を行ったときにねじ部が塑性変形し、ねじ部の気密性が低下するので好ましくない。

【0032】さらに、上述のような拡張用金属管接合体は、端部近傍の内径が拡張されていない金属管を突き合わせ、接合部近傍が横膨出するような接合条件で拡散接合することによっても製造することができる。この場合、接合部近傍の横膨出率が1.04以上となるように拡散接合することが望ましい。横膨出率が1.04未満になると、拡張を行う際に、接合部から亀裂が発生するおそれがあるので好ましくない。

【0033】上記構成を有する本発明に係る拡張用金属管接合体は、接合部の内径が非接合部の内径より大きくなっているため、このような拡張用金属管接合体を、マンドレル等を用いて拡張した場合に、接合部の塑性歪を、非接合部の塑性歪より小さく抑えることができる。

【0034】そのため、例えば、端部内径が予め所定の

端部拡張率で拡張された金属管を拡散接合法又は溶接法で接合し、得られた金属管接合体を拡張した場合において、接合界面近傍に熱影響部が発生し、接合界面近傍の变形能が低下している場合であっても、拡張により接合部に亀裂が発生しにくくなる。

【0035】また、端部内径が拡張されていない金属管を突き合わせ、拡散接合時の加圧力により、接合部を所定の横膨出率で樽型に塑性変形させて金属管接合体とし、これを拡張した場合に、接合部における亀裂の発生が抑制されるだけでなく、金属管の端部内径を拡張する工程が不要となるという利点がある。

【0036】さらに、端部内径が所定の端部拡張率で拡張された金属管をねじ接合法により接合して金属管接合体とした場合において、拡張率が前記端部拡張率以下となるように前記金属管接合体を拡張した場合に、接合部が塑性変形することがない。そのため、ねじの弛みに起因する気密性の低下が生じない。

【0037】また、本発明に係る拡張用金属管接合体は、接合部近傍の内径が、非接合部の内径より大きくなっているため、接合部近傍における变形抵抗が小さくなる。そのため、拡張作業を円滑に行うことができ、しかも拡張作業の省動力化も図られる。

【0038】さらに、金属管の端部を予め所定の端部拡張率で拡張し、拡張された金属管を接合して金属管接合体とした場合には、拡張により少なくとも各金属管の内径を揃えることができる。そのため、外径あるいは肉厚が所定の寸法公差内でばらついている金属管を用いて金属管接合体を作製した場合であっても、接合部の内周面側に発生する段差を小さくすることができ、強度、疲労特性、及び耐食性に優れた金属管接合体を得ることが可能となる。

【0039】

【発明の実施の形態】以下に、本発明の実施の形態について図面を参照しながら詳細に説明する。図1は、本発明の第1の実施の形態に係る拡張用金属管接合体の製造方法（以下、これを「方法A」という）を示す工程図である。図1において、方法Aは、拡張工程と、端面加工工程と、拡散接合工程とを備えている。

【0040】まず、拡張工程について説明する。拡張工程は、図1(a)に示すような、円筒状の金属管30の内、両端の内径のみを適当な工具等を用いて拡大させ、図1(b)に示すように、端部の内径 $d_1$ が中央部の内径 $d_2$ より大きくなっている金属管30に加工する工程である。

【0041】ここで、本発明に用いられる金属管30は、後述する拡張に耐える変形能を有する材料であれば良く、その材質、寸法等については、特に限定されるものではない。例えば、機械的特性のみが要求される用途に用いられる金属管接合体にあっては、金属管30として炭素鋼を用いることができる。また、例えば、ライン

パイプ、油井管等、強度と耐食性の双方が要求される用途にあっては、マルテンサイト系ステンレス鋼、二相ステンレス鋼、オーステナイト系ステンレス鋼等のステンレス鋼、Ti合金等を用いることができる。

【0042】また、本発明においては、各金属管30の拡張前の内径の最小値に対する、拡張後の金属管30の内径の増分を端部拡張率と呼び、次の数1の式で定義する。

【0043】

$$\text{【数1】端部拡張率(\%)} = (d_1 - d_{0.1}) \times 100 / d_{0.1}$$

但し、 $d_1$  : 金属管30端部の拡張後の内径

$d_{0.1}$  : 金属管30端部の拡張前の内径の最小値

【0044】方法Aの場合、端部拡張率は、5%以上が望ましい。端部拡張率が5%未満であると、後述する拡張工程において、接合部を大きく塑性変形させる必要が生じ、接合部に亀裂が発生するおそれがあるので好ましくない。また、端部拡張率が5%未満であると、各金属管30の寸法精度によっては、接合部に大きな段差が発生し、疲労強度が低下する場合があるので好ましくない。

【0045】これは、金属管30の内径が所定の寸法公差内でばらついている場合において、端部拡張率が5%未満になると、拡張前の内径 $d_0$ が、拡張後の内径 $d_1$ より小さい金属管のみが拡張されるようになり、 $d_1$ より大きい内径を有する金属管が拡張されないおそれがあるためである。

【0046】なお、端部拡張率の計算に用いられる内径の最小値 $d_{0.1}$ としては、安全率を見込むという点では、接合に用いられる金属管の規格から予測される最小値を用いることが望ましいが、実測値を用いても良い。

【0047】また、端部拡張率は、接合部の塑性変形を小さくし、亀裂の発生を抑制するという点では、大きい程良い。従って、金属管30の加工の容易性、得られる金属管接合体の用途等に応じて、後述する拡張率以下の範囲内において、最適な端部拡張率で拡張を行えばよい。

【0048】また、拡張により内径が拡大した部分の長さ(以下、これを「拡張長さ」といい、図1(b)中、「L」で表示。)は、金属管30の加工の容易性、用途等を考慮して任意に選択すればよいが、後述する拡張工程における変形抵抗を小さくし、拡張作業の省動力化を図るという点では、長い程良い。

【0049】さらに、拡張方法も、特に限定されるものではなく、種々の方法を用いることができる。通常は、数1の式に示す $d_1$ に相当する外径を有するマンドレルあるいはプラグ等を、所定の長さだけ、金属管30の端部に挿入し、端部内径を拡張すればよい。

【0050】次に、端面加工工程について説明する。端

面加工工程は、図1(c)に示すように、拡張工程により端部内径が拡張された金属管30の端面を所定の表面粗さに機械加工する工程である。これは、金属管30の端面の表面粗さが粗いと、後述する拡散接合工程において、接合界面が十分に密着せず、高い接合強度が得られないためである。

【0051】なお、端面の加工方法は、特に限定されるものではなく、研削加工、ラッピング加工等、各種の方法を用いることができる。また、拡張後も金属管30の端面の表面粗さが所定の範囲に維持されている場合には、端面加工工程は必ずしも必要ではなく、省略することもできる。

【0052】次に、拡散接合工程について説明する。拡散接合工程は、拡張工程において端部内径が拡張され、さらに端面加工工程において、端面が所定の表面粗さに加工された金属管30を突き合わせ、金属管30、30同士を拡散接合させる工程である。

【0053】ここで、拡散接合法には、金属管30を直接突き合わせ、固相状態を維持しながら元素の拡散を行わせる固相拡散接合と、接合界面にインサート材を介挿し、インサート材を一時的に融解させながら元素の拡散を行わせる液相拡散接合とがあるが、いずれの方法を用いてもよい。

【0054】特に、液相拡散接合は、固相拡散接合に比して、短時間で母材と同等の強度を有する接合体が得られるので、接合方法として好適である。図1(d)に、金属管30、30の接合界面にインサート材36を介挿し、液相拡散接合法により接合された金属管接合体32の一例を示す。

【0055】また、拡散接合の条件は、使用する金属管30の材質に応じて最適な範囲を選択すればよい。具体的には、以下の条件下で行うとよい。

【0056】まず、接合面の表面粗さ $R_{max}$ は、50 $\mu m$ 以下が好ましい。接合面の表面粗さ $R_{max}$ が50 $\mu m$ を超えると、接合面において金属管30同士が十分に密着せず、高い接合強度が得られないので好ましくない。高い接合強度を得るという点では、表面粗さ $R_{max}$ は小さい程良い。

【0057】また、使用するインサート材36は、融点が1200℃以下であるNi系合金又はFe系合金が好適である。インサート材36の融点が1200℃を超えると、高い接合温度が必要となるので、接合中に母材を溶融させたり、あるいはインサート材36の未溶融に起因する未接合部が発生するので好ましくない。

【0058】また、使用するインサート材36の厚さは、100 $\mu m$ 以下が好ましい。インサート材36の厚さが100 $\mu m$ を超えると、接合界面における元素の拡散が十分に行われず、接合強度が低下するので好ましくない。

【0059】なお、インサート材36の形状は、特に限

定されるものではなく、厚さ100 $\mu$ m以下の箔状のインサート材36を接合界面に介挿してもよく、あるいは、厚さが100 $\mu$ m以下となるように、粉末状もしくは鱗片状のインサート材36を接合界面に散布したり、ペースト状にして接合界面に塗布してもよい。

【0060】接合雰囲気は、非酸化性雰囲気が好ましい。酸化性雰囲気下で拡散接合を行うと、接合界面近傍が酸化し、接合強度が低下するので好ましくない。

【0061】接合温度は、1250℃以上1400℃以下の範囲が好適である。接合温度が1250℃未満になると、インサート材36が部分的に溶融しなかったり、あるいは元素の拡散が十分に行われず、接合強度が低下するので好ましくない。また、接合温度が1400℃を超えると、母材が溶融するおそれがあるので好ましくない。

【0062】接合温度における保持時間は、30秒以上300秒以下が好適である。保持時間が30秒未満であると、接合界面における元素の拡散が不十分となり、接合強度が低下するので好ましくない。また、保持時間が300秒を超えると、作業効率が低下するので好ましくない。

【0063】さらに、接合界面に付与する加圧力は、1.5MPa以上5MPa以下が好適である。加圧力が1.5MPa未満であると、接合界面の密着が不十分となり、接合強度が低下するので好ましくない。

【0064】また、方法Aにおいては、金属管を接合した後、後述する拡管工程において金属管接合体の拡管を行うので、接合後に接合部近傍が若干変形していてもよい。但し、拡径工程における内径の増分と、接合時の変形に起因する内径の増分の総和が、後述する拡管工程における拡管率を超えると、拡管後も接合界面近傍に凹凸が残る、接合強度を低下させる原因となる。従って、方法Aにおいては、接合部近傍が過大に変形しないよう、加圧力は、5MPa以下とするのが好ましい。

【0065】また、拡散接合を行う際の加熱方法としては、高周波誘導加熱、高周波直接通電加熱、抵抗加熱等の各種の方法を用いることができる。中でも高周波誘導加熱及び高周波直接通電加熱は、比較的大きな被接合材であっても容易に加熱でき、加熱効率が高く、極めて短時間に接合温度まで加熱できるので、加熱方法として特に好適である。

【0066】ただし、高周波誘導加熱又は高周波直接通電加熱に用いる高周波電流としては、周波数が100kHz以下のものを用いるのが好ましい。周波数が100kHzを超えると、表皮効果により表面のみが加熱され、接合面全面が均一に加熱されないのが好ましくない。

【0067】次に、このようにして得られた拡管用金属管接合体の拡管工程について説明する。拡管工程は、上述した拡径工程、端面加工工程及び拡散接合工程にお

て製造された金属管接合体32の拡管を行い、金属管接合体32の内径を一様の大きさにする工程である。

【0068】具体的には、図2(a)に示すように、接合部及び非接合部の内径が、それぞれ $d_1$ 及び $d_2$ である金属管接合体32の一端からマンドレル34を挿入し、図2(b)に示すように、金属管接合体32の他端に向かってマンドレル34を移動させ、金属管接合体32の内径を $d_2$ まで拡大させればよい。本発明においては、拡管前の非接合部の内径の最小値に対する拡管後の内径の増分を拡管率と呼び、次の数2の式で定義する。

【0069】

【数2】拡管率(%) =  $(d_2 - d_{0.1}) \times 100 / d_{0.1}$

但し、 $d_2$  ; 拡管後の非接合部の内径

$d_{0.1}$  ; 拡管前の非接合部の内径の最小値

【0070】なお、方法Aの場合、拡管率は、金属管30の変形能や、金属管接合体32の用途等を考慮して、任意に選択すればよい。また、接合条件が適切であれば、接合部近傍の変形能を高く維持することができるので、端部拡径率よりも大きな拡管率で拡管することもできる。さらに、拡管前の非接合部の内径の最小値 $d_{0.1}$ として、規格から予測される最小値を用いても良く、実測値を用いても良い点は、数1の式と同様である。

【0071】次に、方法Aの作用について説明する。所定の長さ及び内径を有する金属管30(図1(a))の端部を、所定の端部拡径率及び所定の拡径長さ $L_1$ で拡径し(図1(b))し、端面を所定の表面粗さに機械加工した後(図1(c))、金属管30同士を拡散接合すると、図1(d)に示すように、接合部の内径 $d_1$ が非接合部の内径 $d_2$ より大きくなっている金属管接合体32を得ることができる。

【0072】このような金属管接合体32の一端にマンドレル34を挿入し、他端に向かってマンドレル34を移動させると、金属管接合体32の内径が拡大し、図2(b)に示すように、一定の内径 $d_2$ を有する金属管接合体32を得ることができる。

【0073】この時、拡管前の接合部の内径 $d_1$ は、非接合部の内径 $d_2$ より大きくなっているため、拡管時における接合部の塑性歪は、非接合部の塑性歪より小さくなる。そのため、拡散接合の際に熱影響部が発生し、接合部の変形能が低下している場合であっても、拡管により接合部に亀裂が発生しにくくなる。

【0074】また、接合部の内径 $d_1$ が非接合部の内径 $d_2$ より大きいために、接合部近傍の変形抵抗が小さくなる。この変形抵抗の減少量は、接合部の内径 $d_1$ が大きくなるほど、あるいは拡径長さ $L_1$ が長くなるほど、大きくなる。そのため、拡管の際にマンドレル34が受ける摩擦抵抗の総和は、一様な内径を有する金属管接合体を拡管する場合に比較して小さくなり、拡管作業の省

動力化が図られる。

【0075】さらに、各金属管30の外径及び肉厚が寸法公差内でばらついている場合であっても、金属管30の端部近傍の内径を拡張し、各金属管30の内径を揃えた後に接合すれば、金属管接合体32の接合部の内周面に発生する段差を小さくすることができる。そのため、このような金属管接合体32は、拡張を行っても、接合部から段差に起因する亀裂が発生するおそれが少ない。また、応力集中や、腐食物質の滞留が起りにくくなるので、拡張された金属管接合体32の強度、疲労特性及び耐食性が低下することもない。

【0076】なお、上述の方法Aにおいては、接合法として拡散接合法を用いているが、接合法として、アーカ溶接法を用いても良く、これにより同様の効果を得ることができる（以下、これを「方法A'」という）。この場合、拡張工程において、金属管30の端部近傍の内径を所定の端部拡張率で拡張し、端面加工工程において金属管30の端面に開先を形成し、これを突き合わせで開先に溶融金属を肉盛りすればよい。

【0077】次に、本発明の第2の実施の形態に係る拡張用金属管接合体の製造方法について説明する。図3は、本発明の第2の実施の形態に係る拡張用金属管接合体の製造方法（以下、これを「方法B」という）を示す工程図である。図3において、方法Bは、拡張工程と、ねじ加工工程と、締結工程とを備えている。

【0078】拡張工程は、上述した方法Aと同様に、図3(a)に示すような、円筒状の金属管40の内、端部近傍の内径のみを適当な工具等を用いて拡大させることにより、図3(b)に示すように、端部近傍の内径が所定の端部拡張率で拡張された金属管40に加工する工程である。

【0079】但し、方法Bの場合、端部拡張率は、10%以上が望ましい。端部拡張率が10%未満であると、後述する拡張工程において、接合部を大きく塑性変形させる必要が生じるが、ねじ接続法により締結された接合部を塑性変形させると、ねじが弛み、気密性が低下するので好ましくない。

【0080】なお、金属管40として拡張に耐える変形能を有するあらゆる材料を用いることができる点、拡張長さし、は金属管40の加工の容易性等を考慮して任意に選択すればよい点、及び拡張方法として種々の方法を用いることができる点は、上述した方法Aと同様である。

【0081】次に、ねじ加工工程においては、図3(c)に示すように、拡張工程により端部内径が拡張された金属管40の端部に外ねじ40aが形成される。なお、ねじ接続法の場合、接合部で支えることができる荷重はねじの長さし、に依存するので、ねじの長さし、は、金属管接合体42に要求される特性に応じて、任意に定めることができる。

【0082】次に、締結工程においては、拡張工程において端部内径が拡張され、さらにねじ加工工程において、端部に外ねじ40aが形成された金属管40同士が、継手44を介して、締結される工程である。継手44には、金属管40に形成された外ねじ40aと螺合可能な内ねじ44aが形成されている。このようにして得られた金属管接合体42を図3(d)に示す。

【0083】製造された金属管接合体42は、方法Aにより得られた金属管接合体32と同様に、拡張が行われ、金属管接合体42の内径が一様の大きさ $d_2$ に拡大される。具体的には、図4(a)に示すように、金属管接合体42の一端からマンドレル34を挿入し、図4(b)に示すように、金属管接合体42の他端に向かってマンドレル34を移動させることにより、金属管接合体42の内径を所定の拡張率で拡張させる。

【0084】ここで、方法Bの場合、金属管接合体42の拡張は、金属管40の端部拡張率以下の拡張率で行うことが望ましい。拡張率が端部拡張率を超えると、拡張時に接合部が塑性変形し、ねじが緩むおそれがあるので好ましくない。また、接合部近傍は、継手44があるために肉厚となっている。そのため、端部拡張率を超える拡張率で拡張するのは、変形抵抗の増大を招き、円滑な拡張作業が困難となるので好ましくない。

【0085】次に、方法Bの作用について説明する。予め端部拡張率が10%以上となるように、金属管40の端部近傍の内径を拡張し、金属管40同士をねじ接続法により接合すると、接合部の内径 $d_1$ が非接合部の内径 $d_0$ より大きくなっている金属管接合体42を容易に得ることができる。

【0086】このようにして得られた金属管接合体42を、マンドレル等を用いて拡張すれば、方法Aと同様に、接合部近傍の変形抵抗が小さくなる。そのため、均一な内径を有する金属管接合体を拡張する場合に比して、拡張作業の省動力化が図られる。しかも、端部拡張率以下の拡張率で拡張が行われるので、ねじの塑性変形に起因する気密性の低下という、ねじ接続法特有の問題も解決される。

【0087】次に、本発明の第3の実施の形態に係る拡張用金属管接合体の製造方法について説明する。図5(a)～(c)は、本発明の第3の実施の形態に係る拡張用金属管接合体の製造方法（以下、これを「方法C」という）を示す工程図である。

【0088】方法Cの場合、金属管50として、拡張に耐える変形能を有するあらゆる材料を用いることができる点は、方法Aと同様であるが、円筒状の金属管50の端部を拡張することなく、そのまま拡散接合を行い、拡散接合の際に、接合部近傍を樽型に変形させる点が異なっている。

【0089】すなわち、図5(a)に示すような円筒状の金属管50の端部を拡張することなく、そのまま突き

合わせて加圧し(図5(b))、熱源54を介して接合部近傍を加熱する。なお、接合方法は、図5(b)に示すように、接合界面にインサート材36を介挿させて接合を行う液相拡散接合法でも良く、あるいはインサート材36を用いない固相拡散接合を用いてもよい。

【0090】この時、接合条件が適切であると、接合界面において拡散接合が進行すると同時に、接合界面近傍が樽型に変形し、図5(c)に示すように、接合部の内径 $d_1$ が非接合部の内径 $d_0$ より大きくなっている金属管接合体52を得ることができる。本発明においては、非接合部の金属管の内径の最小値に対する、拡散接合後の接合部の内径の増分を横彫出率と呼び、次の数3の式で定義する。

【0091】

【数3】横彫出率 $= d_1 / d_0 \dots$

但し、 $d_1$  : 接合部の内径

$d_0$  : 非接合部の内径の最小値

【0092】方法Cの場合、横彫出率は、1.04以上が望ましい。横彫出率が1.04未満であると、後述する拡管工程において、接合部を大きく塑性変形させる必要が生じ、接合部に亀裂が発生するおそれがあるので好ましくない。

【0093】なお、非接合部の内径の最小値 $d_0$ として、規格から予測される最小値を用いても良く、実測値を用いても良い点は、数1の式と同様である。また、横彫出率は、拡管時における接合部の塑性歪を小さくし、亀裂の発生を抑制するという点では、大きい程良い。さらに、拡散接合により内径が増加した部分の長さ(以下、これを「彫出長さ」といい、図5(c)中、「L<sub>1</sub>」で表示。)は、拡管工程における変形抵抗を小さくするという点では、長い程良い。

【0094】また、方法Cの場合、拡散接合時に接合界面近傍を積極的に塑性変形させる必要があるため、拡散接合の条件も、要求される横彫出率等が得られる条件を選択する必要がある。具体的には、以下の条件下で接合するとよい。

【0095】すなわち、接合温度は、1250℃以上1400℃以下の範囲が好適である。接合温度が1250℃未満になると、インサート材が部分的に溶融しなかったり、あるいは元素の拡散が十分に行われず、接合強度が低下するおそれがある。また、接合温度が低すぎると、金属管50の変形抵抗が大きくなり、所定の横彫出率が得られないので好ましくない。さらに、接合温度が1400℃を超えると、母材が溶融するおそれがあるので好ましくない。

【0096】接合温度における保持時間は、60秒以上が好適である。保持時間が60秒未満であると、大きな横彫出率を得ることができないので好ましくない。なお、横彫出率を大きくするという点では、保持時間は長い程良いので、所望の横彫出率が得られるように、保

持時間を調節するとよい。

【0097】また、接合界面に付与する加圧力は、2MPa以上が好適である。加圧力が2MPa未満であると、大きな横彫出率を得ることができないので、好ましくない。なお、方法Cの場合、横彫出率を大きくするという点では、加圧力は大きい程良く、5MPa以上であっても良い。但し、横彫出率が拡管率を超えると、拡管後も、接合界面近傍に凹凸が残り、接合強度が低下する。従って、加圧力は、横彫出率が拡管率以下となるように調節することが望ましい。

【0098】さらに、接合部近傍の加熱幅は、20mm以上が好適である。加熱幅が20mm未満になると、横彫出率が小さくなると共に、彫出長さ $L_1$ も短くなるので好ましくない。拡管時の変形抵抗をより小さくするという点では、横彫出率が大きく、かつ彫出長さ $L_1$ も長い方が良く、そのためには、加熱幅は長い方がよい。

【0099】なお、接合面の表面粗さ $R_{max}$ は、50 $\mu$ m以下が好ましい点、使用するインサート材は、融点が1200℃以下である厚さ100 $\mu$ m以下のNi系合金又はFe系合金が好ましい点、インサート材の形状は、特に限定されるものではなく、箔状、粉末状あるいは薄片状のインサート材を用いることができる点は、方法Aと同様である。

【0100】また、接合雰囲気は、非酸化性雰囲気为好ましい点、及び拡散接合を行う際の熱源としては、周波数100kHz以下の高周波電流を用いた高周波誘導加熱、又は高周波直接通電加熱が好ましい点も、方法Aと同様である。

【0101】次に、上述のようにして製造された所定の横彫出率を有する金属管接合体52の拡管が行われる。具体的には、図5(d)に示すように、金属管接合体52の一端からマンドレル34を挿入し、金属管接合体52の他端に向かってマンドレル34を移動させればよい。

【0102】なお、拡管率は、金属管50の変形能や、金属管接合体52の用途等を考慮して、任意に選択すればよい点、及び、接合条件が適切であれば、接合部近傍の変形能を高く維持することができるので、端部拡管率よりも大きな拡管率で拡管することもできる点は、方法Aと同様である。

【0103】次に、方法Cの作用について説明する。端部内径が拡管されていない金属管50を突き合わせ、金属管50同士を拡散接合すると同時に、接合部近傍を積極的に塑性変形させると、接合部の内径 $d_1$ が非接合部の内径 $d_0$ より大きくなっている金属管接合体52を容易に得ることができる。

【0104】このようにして得られた金属管接合体52を、マンドレル等を用いて拡管すれば、方法Aと同様に、接合部近傍の変形抵抗が小さくなる。そのため、均一な内径を有する金属管接合体を拡管する場合に比し

て、拡張作業を円滑に行うことができ、拡張作業の省動力化も図られる。

【0105】また、接合部の内径が大きくなっていることにより、拡張時における接合部の塑性歪を小さくすることができる。そのため、方法Aと同様に、接合部近傍に熱影響部が発生し、変形能が低下している場合であっても、拡張により接合部に亀裂が発生しにくくなり、強度及び気密性に優れた金属管接合体を得ることができる。

【0106】（実施例1）方法Aを用いて、金属管接合体の拡張を行った。金属管には、アメリカ石油協会グレードH40（以下、これを「API H40」と表記する）からなる外径7インチ（178mm）、肉厚0.231インチ（6mm）の炭素鋼管を用い、この鋼管の端部内径を、端部拡張率が5%となるように拡張した。

【0107】次に、拡張された金属管の端面を表面粗さ $R_{max}$ が30 $\mu m$ 以下となるように仕上げ、金属管の接合界面に、JIS BNi-3相当の組成を有する融点1050℃、厚さ50 $\mu m$ のNi系合金箔を介挿し、液相拡散接合を行った。さらに、得られた金属管接合体を、拡張率が25%となるようにマンドレルを用いて拡張した。

【0108】なお、接合部の加熱方法には、周波数3kHzの高周波電流を用いた高周波誘導加熱法を用いた。また、接合条件は、接合温度1300℃、保持時間180秒、加圧力4MPaとし、Ar雰囲気中で接合を行った。

【0109】（実施例2～3、比較例1、2）金属管30の端部拡張率を、それぞれ、0%（比較例1）、3%（比較例2）、20%（実施例2）、及び25%（実施例3）とした以外は、実施例1と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0110】実施例1～3、及び比較例1～2で得られた金属管接合体について、接合後に接合部の内周面側に発生した段差の最大値（以下、これを単に「最大段差」という）を測定した。また、拡張後の接合部表面について浸透探傷試験を行い、割れの有無を調べた。さらに、拡張された接合体の外周面に発生した段差のみをグラインダーにより研削して0.5mm以下とした後、この接合体から、API 1104号試験片を切り出し、引張試験を行った。結果を表1に示す。

【0111】

【表1】

実験 No		比較例 1	比較例 2	実施例 1	実施例 2	実施例 3
鋼管	材質	API H40	API H40	API H40	API H40	API H40
	寸 外径(インチ)	7.00	7.00	7.00	7.00	7.00
	法 肉厚(インチ)	0.231	0.231	0.231	0.231	0.231
端部拡張率 (%)		0	3	5	20	25
接合面表面粗さ (Rmax: $\mu\text{m}$ )		30	30	30	30	30
インサート材	材質	BNi-3	BNi-3	BNi-3	BNi-3	BNi-3
	融点 (°C)	1050	1050	1050	1050	1050
	厚さ ( $\mu\text{m}$ )	50	50	50	50	50
	形態	箔	箔	箔	箔	箔
接合温度 (°C)		1300	1300	1300	1300	1300
保持時間 (s)		180	180	180	180	180
加圧力 (MPa)		4.0	4.0	4.0	4.0	4.0
接合雰囲気		Ar	Ar	Ar	Ar	Ar
接合部の加熱方法		高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)
接合部の最大段差 (mm)		4.0	1.0	0.5	0.5	0.5
拡張率 (%)		25	25	25	25	25
接合部表面の浸透探傷試験結果		割れ有り	割れ有り	割れ無し	割れ無し	割れ無し
引張試験結果	引張強さ (MPa)	283	467	716	716	717
	破断位置	接合界面	接合界面	母材	母材	母材
総合評価		×	△	○	○	○

【0112】端部拡張率を0%とした比較例1では、最大段差は、4mmに達した。また、拡張後の浸透探傷試験において、接合部に多数の亀裂が認められた。さらに、引張強度は283MPaの低強度を示し、試験片は接合界面から破断した。

【0113】端部拡張率を3%とした比較例2では、最大段差は、1mmに減少した。また、拡張後の浸透探傷試験において、接合部にはかなりの亀裂が認められたが、亀裂の数は比較例1より少なかった。これに対応して、引張強度は、467MPaまで向上したが、試験片は、接合界面から破断した。

【0114】これに対し、端部拡張率をそれぞれ、5%、20%、及び25%とした実施例1、2及び3では、最大段差は、いずれも0.5mmに減少した。ま

た、拡張後の浸透探傷試験において、いずれも接合界面には亀裂は認められなかった。さらに、接合強度は、いずれも母材と同等である700MPa以上を示し、試験片は、母材側から破断した。

【0115】以上の結果から、金属管を接合する前に、金属管の端部内径を所定の端部拡張率以上の値となるように拡張すると、最大段差を小さくすることができるとがわかった。また、端部拡張率を大きくするほど、拡張時に接合部に亀裂が発生しにくくなり、接合強度の高い金属管接合体が得られることがわかった。

【0116】(実施例4)方法Aを用いて、金属管接合体の拡張を行った。金属管には、API H40からなる外径7インチ(178mm)、肉厚0.231インチ(6mm)の炭素鋼管を用い、この鋼管の端部内径を、

端部拡張率が15%となるように拡張した。

【0117】次に、拡張された金属管の端面を表面粗さ  $R_{max}$  が  $30\mu m$  以下となるように仕上げ、金属管の接合界面に、融点  $1200^{\circ}C$ 、厚さ  $40\mu m$  の  $Fe-3B-3Si-1C$  合金箔を介挿し、液相拡散接合を行った。さらに、得られた金属管接合体を、拡張率が25%となるようにマンドレルを用いて拡張した。

【0118】なお、接合部の加熱方法には、周波数3kHzの高周波電流を用いた高周波誘導加熱法を用いた。また、接合条件は、接合温度  $1250^{\circ}C$ 、保持時間60秒、加圧力4MPaとし、Ar雰囲気中で接合を行った。

【0119】(実施例5) インサート材として、JIS B Ni-5 相当の組成を有する融点  $1140^{\circ}C$ 、厚さ  $40\mu m$  のNi系合金箔を用い、 $1300^{\circ}C$  に120秒保持した以外は、実施例4と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0120】(実施例6) インサート材として、JIS B Ni-5 相当の組成を有する融点  $1140^{\circ}C$ 、厚さ  $40\mu m$  のNi系合金箔を用い、接合温度を  $1400^{\circ}C$ 、保持時間を300秒とした以外は、実施例4と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0121】(比較例3) インサート材として、融点  $1290^{\circ}C$ 、厚さ  $40\mu m$  の  $Fe-2B-1Si$  合金箔を用い、接合温度を  $1400^{\circ}C$ 、保持時間を300秒、加圧力を5MPaとした以外は、実施例4と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0122】実施例4～6、及び比較例3で得られた金属管接合体について、実施例1と同様の手順に従い、最大段差、浸透探傷試験、及び引張試験を行った。結果を表2に示す。

【0123】

【表2】

実験 No		比較例3	実施例4	実施例5	実施例6
鋼管	材質	API H40	API H40	API H40	API H40
	寸 外径(インチ)	7.00	7.30	7.00	7.00
	法 肉厚(インチ)	0.231	0.231	0.231	0.231
端部拡張率(%)		15	15	15	15
接合面表面粗さ ( $R_{max}$ : $\mu m$ )		30	30	30	30
インサート材	材質	Fe-28-1Si	Fe-38-3Si-1C	BNi-5	BNi-5
	融点(°C)	1290	1200	1140	1140
	厚さ( $\mu m$ )	40	40	40	40
	形態	箔	箔	箔	箔
接合温度(°C)		1400	1250	1300	1400
保持時間(s)		300	60	120	300
加圧力(MPa)		5.0	4.0	4.0	5.0
接合雰囲気		Ar	Ar	Ar	Ar
接合部の加熱方法		高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)
接合部の最大段差 (mm)		0.5	0.5	0.5	0.5
拡張率(%)		25	25	25	25
接合部表面の 浸透探傷試験結果		割れ有り	割れ無し	割れ無し	割れ無し
引張試験結果	引張強さ (MPa)	417	719	720	722
	破断位置	接合界面	母材	母材	母材
総合評価		△	○	○	○

【0124】融点が1290℃であるインサート材を用いた比較例3では、保持時間を300秒としたにもかかわらず、拡張後の浸透探傷試験において、接合部に亀裂が認められた。また、引張強度は、417MPaであり、試験片は、接合界面から破断した。これは、インサート材の融点が高いために、接合界面において元素の拡散が十分に行われず、接合界面近傍の変形能が低下しているためと考えられる。

【0125】これに対し、融点が1200℃であるインサート材を用いた実施例4、並びに融点が1140℃であるインサート材を用いた実施例5及び6は、拡張後の浸透探傷試験において、いずれも接合界面には亀裂が認められなかった。また、接合強度は、いずれも母材と同

等である700MPa以上を示し、試験片は、母材側から破断した。

【0126】なお、実施例3～6及び比較例3においては、金属管の端部拡張率をいずれも15%としているので、最大段差は、いずれも0.5mmであった。

【0127】以上の結果から、金属管を液相拡散接合する場合において、融点が1200℃以下のインサート材を用いると、拡張後に、接合部に亀裂が発生することはなく、接合強度の高い金属管接合体が得られることがわかった。

【0128】(実施例7)方法Aを用いて、金属管接合体の拡張を行った。金属管には、API H40からなる外径7インチ(178mm)、肉厚0.231インチ

(6mm)の炭素鋼管を用い、この鋼管の端部内径を、端部拡張率が15%となるように拡張した。

【0129】次に、拡張された金属管の端面を表面粗さ $R_{max}$ が30 $\mu m$ 以下となるように仕上げ、金属管の接合界面に、JIS BNi-5相当の組成を有する融点1140℃の鱗片状Ni系合金を厚さ100 $\mu m$ となるように介挿し、液相拡散接合を行った。さらに、得られた金属管接合体を、拡張率が25%となるようにマンドレルを用いて拡張した。

【0130】なお、接合部の加熱方法には、周波数3k 10 Hzの高周波電流を用いた高周波誘導加熱法を用いた。また、接合条件は、接合温度1300℃、保持時間180秒、加圧力4MPaとし、Ar雰囲気中で接合を行った。

【0131】(実施例8)インサート材として、JIS BNi-5相当の組成を有するNi系合金粉末を用い、これを厚さ30 $\mu m$ となるように金属管の接合界面に介挿し、接合温度に60秒間保持した以外は、実施例7と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0132】(実施例9)インサート材として、JIS

BNi-5相当の組成を有する厚さ40 $\mu m$ のNi系合金箔を用い、接合温度を1250℃、保持時間を60秒とした以外は、実施例7と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0133】(比較例4)インサート材として、JIS BNi-5相当の組成を有する厚さ200 $\mu m$ のNi系合金箔を用い、接合温度を1400℃、保持時間を300秒とした以外は、実施例7と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0134】(比較例5)インサート材として、JIS BNi-5相当の組成を有する厚さ40 $\mu m$ のNi系合金箔を用い、接合温度を1450℃、保持時間を60秒とした以外は、実施例7と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0135】実施例7～9、及び比較例4～5で得られた金属管接合体について、実施例1と同様の手順に従い、最大段差、浸透探傷試験、及び引張試験を行った。結果を表3に示す。

【0136】

20 【表3】

実 験 No		比較例4	実施例7	実施例8	実施例9	比較例5
銅管	材 質	API H40	API H40	API H40	API H40	API H40
	寸 外径(インチ)	7.00	7.00	7.00	7.00	7.00
	法 肉厚(インチ)	0.231	0.231	0.231	0.231	0.231
端部拡張率(%)		15	15	15	15	15
接合面表面粗さ ( $R_{max}$ : $\mu m$ )		30	30	30	30	30
インサート材	材 質	BNi-5	BNi-5	BNi-5	BNi-5	BNi-5
	融点(°C)	1140	1140	1140	1140	1140
	厚さ( $\mu m$ )	200	100	30	40	40
	形態	箔	銅 片	粉 末	箔	箔
接合温度(°C)		1400	1300	1300	1250	1450
保持時間(s)		300	180	60	60	60
加圧力(MPa)		5.0	4.0	4.0	4.0	2.0
接合雰囲気		Ar	Ar	Ar	Ar	Ar
接合部の加熱方法		高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)
接合部の最大段差 (mm)		0.5	0.5	0.5	0.5	0.5
拡張率(%)		25	25	25	25	25
接合部表面の 浸透探傷試験結果		割れ有り	割れ無し	割れ無し	割れ無し	割れ有り
引張 試験 結果	引張強さ (MPa)	588	718	721	718	657
	破断位置	接合界面	母 材	母 材	母 材	接合界面
総合評価		△	○	○	○	△

【0137】インサート材の厚さを200 $\mu m$ とした比較例4では、保持時間を300秒としたにもかかわらず、拡張後の浸透探傷試験において、接合部に亀裂が認められた。また、引張強度は、588MPaであり、試験片は、接合界面から破断した。これは、インサート材が厚いために、インサート材に含まれる元素の拡散が十分に行われず、接合界面近傍の変形能が低下したためと考えられる。

【0138】また、接合温度を1450°Cとした比較例5では、接合部近傍に溶損が発生していた。また、拡張後の浸透探傷試験において、接合部に亀裂が認められた。さらに、引張強度は、657MPaであり、試験片は、接合界面から破断した。

【0139】これに対し、インサート材の厚さを100

40  $\mu m$ 以下とし、かつ接合温度を1400°C以下とした実施例7、8及び9では、いずれも接合部に溶損は認められず、拡張後の浸透探傷試験においても、接合界面には亀裂が認められなかった。また、接合強度は、いずれも母材と同等である700MPa以上を示し、試験片は、母材側から破断した。

【0140】なお、実施例7～9及び比較例4～5においては、金属管の端部拡張率をいずれも15%としているので、最大段差は、いずれも0.5mmであった。

【0141】以上の結果から、金属管を液相拡散接合する場合において、インサート材の厚さを100 $\mu m$ 以下とすると、拡張後に接合部に亀裂が発生することはなく、接合強度の高い金属管接合体が得られることがわかった。また、接合部の溶損を抑制するには、接合温度を

1400℃以下とする必要があることがわかった。

【0142】(実施例10)方法Aを用いて、金属管接合体の拡管を行った。金属管には、API H40からなる外径7インチ(178mm)、肉厚0.231インチ(6mm)の炭素鋼管を用い、この鋼管の端部内径を、端部拡径率が15%となるように拡径した。

【0143】次に、拡径された金属管の端面を表面粗さRmaxが30μm以下となるように仕上げ、金属管の接合界面に、JIS BNi-5相当の組成を有する融点1140℃、厚さ40μmのNi系合金箔を介挿し、液相拡散接合を行った。さらに、得られた金属管接合体を、拡管率が25%となるようにマンドレルを用いて拡管した。

【0144】なお、接合部の加熱方法には、周波数3kHzの高周波電流を用いた高周波誘導加熱法を用いた。また、接合条件は、接合温度1400℃、保持時間30秒、加圧力5MPaとし、Ar雰囲気中で接合を行った。

【0145】(実施例11)接合温度における保持時間を300秒、加圧力を1.5MPaとした以外は、実施

例10と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0146】(比較例6)接合温度における保持時間を15秒とした以外は、実施例10と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0147】(比較例7)インサート材として、JIS BNi-5相当の組成を有する厚さ30μmのNi系合金箔を用い、接合温度における保持時間を300秒、加圧力を1MPaとした以外は、実施例10と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0148】(比較例8)接合温度を1250℃、保持時間を300秒、加圧力を7MPaとした以外は、実施例10と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0149】実施例10~11、及び比較例6~8で得られた金属管接合体について、実施例1と同様の手順に従い、最大段差、浸透探傷試験、及び引張試験を行った。結果を表4に示す。

【0150】

【表4】

実験 No		比較例 8	実施例 10	比較例 7	実施例 11	比較例 8
鋼管	材質	API H40	API H40	API H40	API H40	API H40
	寸 外径 (インチ)	7.00	7.00	7.00	7.03	7.00
	法 肉厚 (インチ)	0.231	0.231	0.231	0.231	0.231
端部直径率 (%)		15	15	15	15	15
接合面表面粗さ (Rmax: $\mu\text{m}$ )		30	30	30	30	30
インサート材	材質	BNi-5	BNi-5	BNi-5	BNi-5	BNi-5
	融点 (°C)	1140	1140	1140	1140	1140
	厚さ ( $\mu\text{m}$ )	40	40	30	40	40
	形態	箔	箔	箔	箔	箔
接合温度 (°C)		1400	1400	1400	1400	1250
保持時間 (s)		15	30	300	300	300
加圧力 (MPa)		5.0	5.0	1.0	1.5	7.0
接合雰囲気		Ar	Ar	Ar	Ar	Ar
接合部の加熱方法		高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)
接合部の最大段差 (mm)		0.5	0.5	0.5	0.5	0.5
拡管率 (%)		25	25	25	25	25
接合部表面の浸透探傷試験結果		割れ有り	割れ無し	割れ有り	割れ無し	割れ有り
引張試験結果	引張強度 (MPa)	563	709	628	714	687
	破断位置	接合界面	母材	接合界面	母材	接合界面
総合評価		△	○	△	○	△

【0151】接合温度における保持時間を15秒とした比較例8では、拡管後の浸透探傷試験において、接合部に亀裂が認められた。また、引張強度は、563MPaであり、試験片は、接合界面から破断した。これは、保持時間が短いために、接合界面における元素の拡散が十分に行われず、接合界面近傍の変形能が低下したためと考えられる。

【0152】また、加圧力を1MPaとした比較例7では、接合温度における保持時間を300秒としたにもかかわらず、拡管後の浸透探傷試験において、接合部に亀裂が認められた。また、引張強度は、628MPaであり、試験片は、接合界面から破断した。これは、加圧力が低いために、接合界面が十分に密着せず、部分的に未接合部が発生し、これにより接合界面全体の変形能が低

下したためと考えられる。

【0153】さらに、加圧力を7MPaとした比較例8では、接合温度を1250°Cまで下げたにもかかわらず、接合部近傍に過大な変形が生じた。また、拡管後の浸透探傷試験において、接合部に亀裂が認められた。さらに、引張強度は、687MPaであり、試験片は、接合界面から破断した。

【0154】これに対し、加圧力を5MPa、保持時間を30秒とした実施例10、及び加圧力を1.5MPa、保持時間を300秒とした実施例11では、いずれも拡管後の浸透探傷試験においても、接合界面には亀裂が認められなかった。また、接合強度は、いずれも母材と同等である700MPa以上を示し、試験片は、母材側から破断した。

【0155】なお、実施例10～11及び比較例6～8においては、金属管の端部拡張率をいずれも15%としているので、最大段差は、いずれも0.5mmであった。

【0156】以上の結果から、金属管を液相拡散接合する場合において、加圧力を1.5MPa以上5MPa以下とすると、拡張後に接合部に亀裂が発生することはない、接合強度の高い金属管接合体が得られることがわかった。

【0157】（実施例12）方法Aを用いて、金属管接合体の拡張を行った。金属管には、マルテンサイト系ステンレス鋼の一種である、アメリカ石油協会グレードLC52-1200（以下、これを「LC52-1200」という）からなる外径10.75インチ（269mm）、肉厚0.5インチ（13mm）の鋼管を用い、この鋼管の端部内径を、端部拡張率が15%となるように拡張した。

【0158】次に、拡張された金属管の端面を表面粗さRmaxが50μm以下となるように仕上げ、金属管の接合界面に、JIS BNi-5相当の組成を有する融点1140℃、厚さ40μmのNi系合金箔を介挿し、液相拡散接合を行った。さらに、得られた金属管接合体を、拡張率が25%となるようにマンドレルを用いて拡張した。

【0159】なお、接合部の加熱方法には、周波数3kHzの高周波電流を用いた高周波誘導加熱法を用いた。また、接合条件は、接合温度1300℃、保持時間12

0秒、加圧力4MPaとし、Ar雰囲気中で接合を行った。

【0160】（実施例13）接合温度を1350℃、保持時間を210秒、加圧力を3.5MPaとし、誘導コイルに流す高周波電流の周波数を100kHzとした以外は、実施例12と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0161】（実施例14）接合温度を1350℃、保持時間を210秒、加圧力を3.5MPaとし、周波数25kHzの高周波電流を用いた高周波直接通電加熱法により接合を行った以外は、実施例12と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0162】（比較例9）接合面の表面粗さRmaxを100μmとし、接合温度を1400℃、保持時間を300秒とした以外は、実施例12と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0163】（比較例10）接合温度における保持時間を300秒、加圧力を5MPaとし、誘導コイルに流す高周波電流の周波数を400kHzとした以外は、実施例12と同様の手順に従い、金属管接合体の製造及び拡張を行った。

【0164】実施例12～14、及び比較例9～10で得られた金属管接合体について、実施例1と同様の手順に従い、最大段差、浸透探傷試験、及び引張試験を行った。結果を表5に示す。

【0165】

【表5】

実験 No		比較例 9	実施例 12	比較例 10	実施例 13	実施例 14
鋼管	材質	LC52-1200	LC52-1200	LC52-1200	LC52-1200	LC52-1200
	寸 外径 (mm)	10.75	10.75	10.75	10.75	10.75
	法 肉厚 (mm)	0.500	0.500	0.500	0.500	0.500
端部拡張率 (%)		15	15	15	15	15
接合面表面粗さ (Rmax: $\mu\text{m}$ )		100	50	30	30	30
インサート材	材質	8Ni-5	8Ni-5	8Ni-5	8Ni-5	8Ni-5
	融点 (°C)	1140	1140	1140	1140	1140
	厚さ ( $\mu\text{m}$ )	40	40	40	40	40
	形態	箔	箔	箔	箔	箔
接合温度 (°C)		1400	1300	1400	1350	1350
保持時間 (s)		300	120	300	210	210
加圧力 (MPa)		5.0	4.0	5.0	3.5	3.5
接合雰囲気		Ar	Ar	Ar	Ar	Ar
接合部の加熱方法		高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (3kHz)	高周波誘導加熱法 (400kHz)	高周波誘導加熱法 (100kHz)	高周波誘導加熱法 (25kHz)
接合部の最大段差 (mm)		0.5	0.5	0.5	0.5	0.5
拡張率 (%)		25	25	25	25	25
接合部表面の浸透探傷試験結果		割れ有り	割れ無し	割れ有り	割れ無し	割れ無し
引張試験結果	引張強度 (MPa)	477	855	431	858	853
	破断位置	接合界面	母材	接合界面	母材	母材
総合評価		×	○	×	○	○

【0166】接合界面の表面粗さ Rmax を  $100\mu\text{m}$  とした比較例 9 では、相対的に高温、高圧、長時間の条件下で拡散接合を行ったにもかかわらず、拡管後の浸透探傷試験において、接合部に亀裂が認められた。また、引張強度は、 $477\text{MPa}$  であり、試験片は、接合界面から破断した。これは、表面粗さが粗いために、接合界面に存在する凹凸を溶融した Ni 合金で充填することができず、これにより接合界面全体の変形能が低下したためと考えられる。

【0167】また、周波数が  $400\text{MPa}$  である高周波電流を用いて誘導加熱した比較例 10 も同様に、相対的に高温、高圧、長時間の条件下で拡散接合を行ったにもかかわらず、拡管後の浸透探傷試験において、接合部に亀裂が認められた。また、引張強度は、 $431\text{MPa}$  で

あり、試験片は、接合界面から破断した。これは、周波数が高いために、接合界面全体が均一に加熱されず、金属管の内周面側に未接合部が発生し、これにより接合界面全体の変形能が低下したためと考えられる。

【0168】これに対し、接合界面の表面粗さ Rmax を  $50\mu\text{m}$  以下とし、周波数が  $100\text{kHz}$  以下の高周波電流を用いた実施例 12～14 では、いずれも拡管後の浸透探傷試験において、接合部に亀裂は認められなかった。また、接合強度は、いずれも母材と同等である  $700\text{MPa}$  以上を示し、試験片は、母材側から破断した。

【0169】なお、実施例 12～14 及び比較例 9～10 においては、金属管の端部拡張率をいずれも 15% としているため、最大段差は、いずれも  $0.5\text{mm}$  であっ

た。

【0170】以上の結果から、金属管を液相拡散接合する場合において、接合界面の表面粗さ  $R_{max}$  を  $50\mu m$  以下とすると、拡管後に接合部に亀裂が発生することではなく、接合強度の高い金属管接合体が得られることがわかった。また、接合界面を高周波誘導加熱又は高周波直接通電加熱する場合において、高周波電流の周波数を  $100kHz$  以下とすると、未接合部の発生に起因する変形脆の低下を抑制できることがわかった。

【0171】（実施例15）方法Bを用いて、金属管接合体の拡管を行った。金属管には、API 40Hからなる外径7インチ（178mm）、肉厚0.231インチ（6mm）の炭素鋼管を用い、この鋼管の端部内径を、端部拡径率が10%となるように拡径した。

【0172】次に、拡径された金属管の端面に外ねじを形成し、この外ねじと螺合可能な内ねじを有する継手を介して、金属管同士を締結した。さらに、得られた金属管接合体を、拡管率が10%となるようにマンドレルを用いて拡管した。

【0173】（実施例16）金属管の端部拡径率を25%とし、拡管率25%で金属管接合体を拡管した以外は、実施例15と同様の手順に従い、金属管接合体の製\*

\* 造及び拡管を行った。

【0174】（実施例18）金属管として、LC52-1200からなる外径10.75インチ（273mm）、肉厚0.5インチ（12.7mm）の鋼管を用い、金属管の端部拡径率を25%とし、拡管率25%で金属管接合体を拡管した以外は、実施例15と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0175】（比較例11）金属管の端部拡径率を0%とした以外は、実施例15と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0176】（比較例12）金属管として、LC52-1200からなる外径10.75インチ（273mm）、肉厚0.5インチ（12.7mm）の鋼管を用い、金属管の端部拡径率を15%とし、拡管率25%で金属管接合体を拡管した以外は、実施例15と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0177】実施例15～17、及び比較例11～12で得られた各金属管接合体について、水圧試験を行った。結果を表6に示す。

【0178】

【表6】

実 験 No	比較例 11	実施例 15	実施例 16	実施例 17	比較例 12
材 質	API H40	API H40	API H40	LC52-1200	LC52-1200
寸 法					
外径 (インチ)	7.00	7.00	7.30	10.75	10.75
肉厚 (インチ)	0.231	0.231	0.231	0.500	0.500
端部拡径率 (%)	0	10	25	25	15
拡管率 (%)	10	10	25	25	20
水圧試験圧力 (psi)	2100	2100	2100	3000	3000
水圧試験結果	漏れ発生	良好	良好	良好	漏れ発生
融合評価	×	○	○	○	×

【0179】端部拡径率を0%とし、金属管接合体を拡管率10%で拡管した比較例11について、圧力2100psiで水圧試験を行ったところ、接合部から水漏れが発生した。

【0180】これに対し、端部拡径率及び拡管率を共に10%とした実施例15、並びに端部拡径率及び拡管率を共に25%とした実施例18は、いずれも圧力2100psiで水圧試験を行っても、接合部から水漏れが発生することはなかった。

【0181】また、端部拡径率を15%とし、金属管接合体を拡管率20%で拡管した比較例12について、圧力3000psiで水圧試験を行ったところ、接合部から水漏れが発生した。

【0182】これに対し、端部拡径率及び拡管率を共に25%とした実施例17では、圧力3000psiで水圧試験を行っても、接合部から水漏れが発生せず、良好な金属管接合体が得られた。

【0183】以上の結果から、ねじ接続法で接合された金属管接合体を拡管する場合において、端部拡径率以下の拡管率で拡管を行うと、気密性に優れた金属管接合体が得られることがわかった。

【0184】（実施例18）方法Cを用いて、金属管接合体の拡管を行った。金属管には、STKM12B（JIS G3445）からなる外径140mm、肉厚7mmの鋼管を用いた。この鋼管の端面を表面粗さ  $R_{max}$  が  $30\mu m$  以下となるように仕上げ、接合界面に、JIS BNi-3相当の組成を有する融点1050℃、厚さ  $50\mu m$  のNi系合金箔を介挿し、拡散接合を行った。さらに、得られた金属管接合体を、拡管率が5～25%となるようにマンドレルを用いて拡管した。

【0185】なお、接合部の加熱方法には、周波数3kHzの高周波電流を用いた高周波誘導加熱法を用い、加熱コイルには、加熱幅が20mmとなるコイルと、40mmとなるコイルの2種類を用いた。また、接合条件

は、接合温度を1250～1350℃、保持時間を60～300秒、加圧力1～4MPaとし、Ar雰囲気中で接合を行った。さらに、横膨出率は、接合条件を変えることにより調整した。

【0188】得られた金属管接合体の横膨出率、膨出長さ、並びに拡張後の割れの有無及び引張強度を表7に示\*

実験 番号	接 合 条 件			横 断 出 率	加 熱 幅	膨 出 長 さ	拡張前 の 引張 強さ	接合部拡張試験結果									
	接合 温度	保持 時間	加圧力					拡張率 5%		拡張率 10%		拡張率 15%		拡張率 20%		拡張率 25%	
								割れ 有無	引張 強さ (MPa)	割れ 有無	引張 強さ (MPa)	割れ 有無	引張 強さ (MPa)	割れ 有無	引張 強さ (MPa)	割れ 有無	引張 強さ (MPa)
1	1250	60	1.0	1.00	20	0	484	無	515	有	—	有	—	有	—	有	—
2	1250	10	1.0	1.00	40	0	483	無	517	有	—	有	—	有	—	有	—
3	1250	60	4.0	1.02	20	40	480	無	511	無	550	無	557	有	—	有	—
4	1250	60	4.0	1.02	40	60	466	無	501	無	543	無	558	無	564	有	—
5	1350	60	2.0	1.04	20	45	485	無	502	無	544	無	551	無	559	有	—
6	1350	60	2.0	1.04	40	90	470	無	482	無	532	無	540	無	549	無	554
7	1300	60	4.0	1.08	20	43	483	無	480	無	541	無	549	無	555	無	562
8	1300	60	4.0	1.08	40	65	488	無	471	無	533	無	540	無	547	無	555
9	1350	60	4.0	1.08	20	47	486	無	466	無	525	無	541	無	547	無	557
10	1350	60	4.0	1.08	40	90	460	無	458	無	478	無	528	無	539	無	551
11	1350	300	4.0	1.14	20	10	482	無	480	無	488	無	505	無	538	無	543
母材	—	—	—	—	—	—	490	無	533	無	563	無	575	無	584	無	591

【0188】表7より、加熱幅の長い加熱コイルを用いるほど、膨出長さが長くなることわかる。すなわち、加熱幅を20mmとすると、膨出長さは、40～50mmとなり、加熱幅を40mmとすると、膨出長さは、80～90mmとなることがわかる。

【0189】また、表7より、膨出長さを40～50mmとした場合、横膨出率が大きくなるほど、より大きな拡張率で拡張を行うことが可能な金属管接合体が得られることがわかる。

【0190】すなわち、横膨出率が1.00の場合、拡張率が10%の時に既に接合界面に割れが発生し、健全な金属管接合体が得られなかった(実験番号1)。横膨出率を1.02とすると、拡張率が15%以下の場合には、健全な金属管接合体が得られたが、拡張率が20%以上になると、接合部に亀裂が発生した(実験番号3)。

【0191】これに対し、横膨出率を1.04以上(実験番号5、7、9、11)とすると、拡張率を20%としても接合部に亀裂が発生することではなく、母材と同等の強度を有する健全な金属管接合体が得られた。

【0192】膨出長さを80～90mmとした場合も同様であり、横膨出率が大きくなるほど、より大きな拡張率で拡張を行うことが可能な金属管接合体が得られてい

\*す。なお、表7には、所定の拡張率で拡張された金属管の非接合部の引張強度(表7中、「母材」と表記)も併せて示した。

【0187】

【表7】

ることがわかる(実験番号2、4、6、8、10)。

【0193】さらに、表7より、横膨出率を同一とした場合、膨出長さが長くなるほど、拡張率の大きな拡張に耐えうる金属管接合体が得られる傾向があることがわかる。すなわち、横膨出率が1.02、膨出長さが40mmである場合には、拡張率20%で拡張すると、接合部に亀裂が発生した(実験番号3)。一方、膨出長さを80mmとした場合には、拡張率20%で拡張しても、接合部に亀裂が発生することではなく、母材と同等の強度を有する健全な接合体が得られている(実験番号4)。

【0194】同様に、横膨出率が1.04、膨出長さが45mmである場合には、拡張率25%で拡張すると、接合部に亀裂が発生した(実験番号5)。一方、膨出長さを90mmとした場合には、拡張率25%で拡張しても、接合部に亀裂が発生することではなく、母材と同等の強度を有する健全な接合体が得られている(実験番号8)。

【0195】以上の結果から、端部が拡張されていない金属管を突き合わせ、拡張接合の際に接合界面近傍を所定の横膨出率で樽型に変形させると、高い拡張率で拡張を行った場合であっても、接合部に亀裂が発生することではなく、接合強度の高い健全な金属管接合体が得られることがわかった。

【0196】（実施例19）方法A'を用いて、金属管接合体の拡管を行った。金属管には、API H40からなる外径7インチ（178mm）、肉厚0.231インチ（6mm）の炭素鋼管を用い、この鋼管の端部内径を、端部拡径率が5%となるように拡径した。

【0197】次に、拡径された金属管の端面に開先を形成し、ガスシールドアーク溶接法により金属管の溶接を行った。さらに、得られた金属管接合体を、拡管率が25%となるようにマンドレルを用いて拡管した。

【0198】なお、溶接は、溶接ワイヤとしてJIS YGW21（φ1.2mm）を用い、シールドガスには、Ar+20%CO<sub>2</sub>の混合ガスを用い、溶接電流280Aの条件下で行った。

\*

\*【0199】（実施例20～21、比較例13～14）金属管30の端部拡径率を、それぞれ、0%（比較例13）、3%（比較例14）、10%（実施例20）、及び15%（実施例21）とした以外は、実施例19と同様の手順に従い、金属管接合体の製造及び拡管を行った。

【0200】実施例19～21、及び比較例13～14で得られた金属管接合体について、実施例1と同様の手順に従い、浸透探傷試験、及び引張試験を行った。結果を表8に示す。

【0201】

【表8】

実験 No		比較例13	比較例14	実施例19	実施例20	実施例21
鋼管	材質	API H40	API H40	API H40	API H40	API H40
	寸 外 径 (インチ)	7.00	7.00	7.00	7.00	7.00
	法 肉 厚 (インチ)	0.231	0.231	0.231	0.231	0.231
端部拡径率 (%)		0	3	5	10	15
溶接方法		ガスシールドアーク溶接法 溶接ワイヤ: JIS YGW21 (φ1.2mm) シールドガス: Ar+20%CO <sub>2</sub> 溶接電流: 280A				
拡管率 (%)		25	25	25	25	25
接合部表面の浸透探傷試験結果		割れ有り	割れ有り	割れ無し	割れ無し	割れ無し
引張試験結果	引張強さ (MPa)	317	495	721	719	720
	破断位置	溶接部	溶接部	母材	母材	母材
総合評価		×	△	○	○	○

【0202】端部拡径率を0%とした比較例13では、拡管後の浸透探傷試験において、接合部に多数の亀裂が認められた。さらに、引張強度は317MPaの低強度を示し、試験片は溶接部から破断した。

【0203】端部拡径率を3%とした比較例14でも同様に、拡管後の浸透探傷試験において、接合部にはかなりの亀裂が認められたが、亀裂の数は比較例13より少なかった。これに対応して、引張強度は、495MPaまで向上したが、試験片は、溶接部から破断した。

【0204】これに対し、端部拡径率をそれぞれ、5%、10%、及び15%とした実施例19、20及び21では、拡管後の浸透探傷試験において、いずれも接合界面には亀裂は認められなかった。さらに、接合強度は、いずれも母材と同等である700MPa以上を示し、試験片は、母材側から破断した。

【0205】以上の結果から、金属管を溶接する前に、

金属管の端部内径を所定の端部拡径率以上の値となるように拡径すると、端部拡径率を大きくするほど、拡管時に接合部に亀裂が発生しにくくなり、接合強度の高い金属管接合体が得られることがわかった。

【0206】以上、本発明の実施の形態について詳細に説明したが、本発明は、上記実施の形態に何ら限定されるものではなく、本発明の要旨を逸脱しない範囲で種々の変改が可能である。

【0207】例えば、拡管に用いるマンドレルの形状は、特に限定されるものではなく、テーパ付のマンドレルを用いてもよく、あるいは、テーパ面にローラを有するマンドレルを用いてもよい。

【0208】また、マンドレルの駆動手段も特に限定されるものではない。例えば、マンドレルの底面に軸を固定し、その軸を用いて、マンドレルを金属管接合体の中に押し込んでもよく、あるいは、マンドレルの底面に液

圧を付与し、液圧により金属管接合体の中を一端から他端に向かって移動させるようにしてもよい。

【0209】また、上記実施の形態では、拡散接合法、ねじ接続法又は溶接法を用いて、接合部の内径が非接合部の内径より大きくなっている金属管接合体を接合しているが、金属管接合体の接合方法は、これらに限定されるものではない。例えば、予め端部近傍の内径が拡張された金属管を、摩擦圧接法により接合して金属管接合体としても良い。

【0210】さらに、本発明に係る拡張用金属管接合体及びその製造方法は、地中に埋設されるケーシング等の油井管及びその製造方法として特に好適であるが、本発明の用途は、油井管に限定されるものではなく、ガス抗井、地熱抗井、温泉井戸、水井戸等に用いられるケーシング、あるいは、地表に敷設されるラインパイプや、プラント用配管及びその製造方法としても用いることができる。これにより上記実施の形態と同様の効果を得ることができる。

【0211】

【発明の効果】本発明に係る拡張用金属管接合体及びその製造方法は、接合部の内径が非接合部の内径より大きくなっている金属管接合体を、マンドレル等の工具を用いて拡張するので、金属管接合体を拡張する際の変形抵抗が小さくなる。そのため、拡張作業を円滑に行うことができ、拡張作業の省動力化も図られるという効果がある。

【0212】また、予め金属管の端部を所定の端部拡張率で拡張し、このような金属管を突き合わせて拡散接合又は溶接すれば、接合部の内径が非接合部の内径より大きくなっている金属管接合体を容易に得ることができる。

【0213】また、このような金属管接合体を拡張した場合には、非接合部の塑性歪に比して、接合部の塑性歪を小さくすることができる。そのため、拡散接合又は溶接した時に熱影響部が発生し、接合部近傍の変形能が低下している場合であっても、接合部に亀裂が発生しにくくなり、強度及び気密性に優れた金属管接合体が得られるという効果がある。

【0214】また、端部内径が所定の端部拡張率で拡張された金属管をねじ接続法により接合して金属管接合体とし、端部拡張率以下の拡張率で金属管接合体を拡張すれば、ねじ部が塑性変形することがないので、ねじの緩みに起因する気密性の低下が生じないという効果がある。

【0215】また、端部が拡張されていない金属管同士を突き合わせ、拡散接合すると同時に接合部を所定の横断面積で樽型に変形させた場合であっても、接合部の内径が非接合部の内径より大きくなっている金属管接合体を容易に得ることができる。そのため、このような金属管接合体を所定の拡張率で拡張すれば、強度及び気密性に優れた金属管接合体が得られるという効果がある。

【0216】さらに、予め金属管の端部を所定の端部拡張率で拡張し、このような金属管を突き合わせて拡散接合した場合には、各金属管の寸法にばらつきがあっても、接合部の内周面側に発生する段差を小さくすることができる。そのため、拡張を行っても、応力集中に起因する亀裂の発生のおそれがなく、また接合部に腐食性物質が滞留することもないので、強度、疲労特性及び耐食性に優れた金属管接合体が得られるという効果がある。

【0217】以上のように、本発明に係る拡張用金属管接合体及びその製造方法によれば、拡張に要する消費エネルギーが少なく、気密性及び強度に優れ、しかも接合部に発生する段差の小さい金属管接合体が容易に得られるので、これを例えば、油井管や、ラインパイプ等に応用すれば、石油掘削作業やパイプ敷設作業の大幅なコストダウンと、信頼性の向上に寄与するものであり、産業上その効果の極めて大きい発明である。

【図面の簡単な説明】

【図1】本発明の第1の実施の形態に係る拡張用金属管接合体の製造方法を示す工程図である。

【図2】図1(d)に示す拡張用金属管接合体の拡張方法を示す工程図である。

【図3】本発明の第2の実施の形態に係る拡張用金属管接合体の製造方法を示す工程図である。

【図4】図2(d)に示す拡張用金属管接合体の拡張方法を示す工程図である。

【図5】図5(a)～(c)は、本発明の第3の実施の形態に係る拡張用金属管接合体の製造方法を示す工程図であり、図5(d)は、図5(c)に示す拡張用金属管接合体の拡張方法を示す図である。

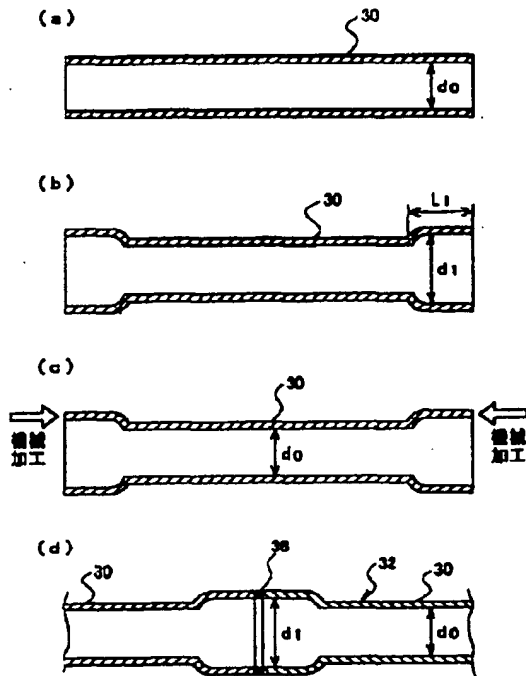
【図6】油井の一般的な構造を示す断面図である。

【図7】ねじ接続法(メカニカルカップリング法)を示す断面図である。

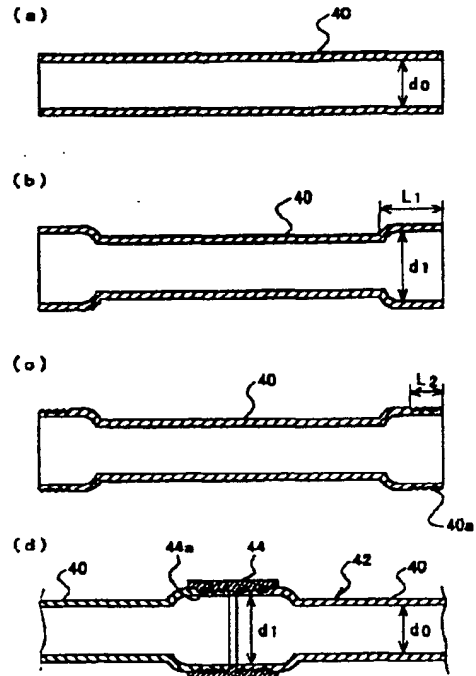
【符号の説明】

30、40、50	金属管
32、42、52	金属管接合体
34	マンドレル

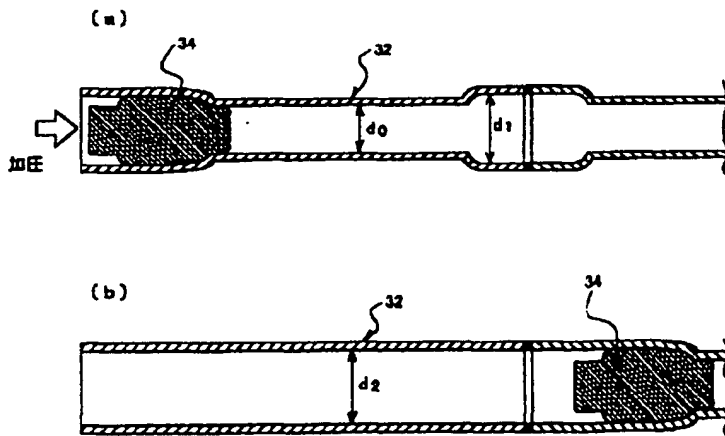
【図1】



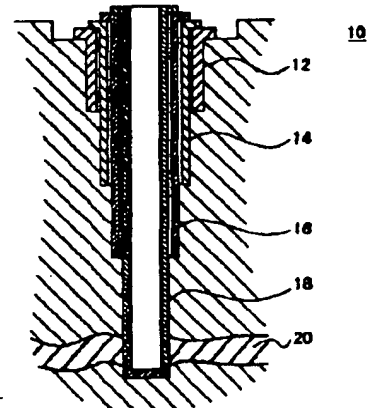
【図3】



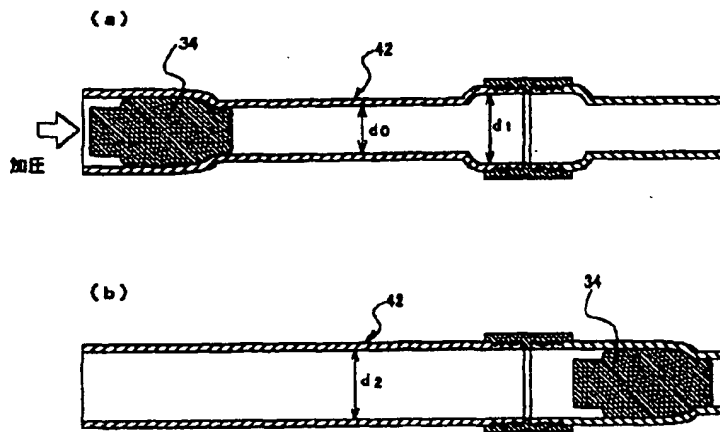
【図2】



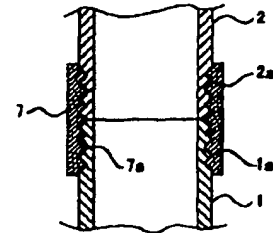
【図6】



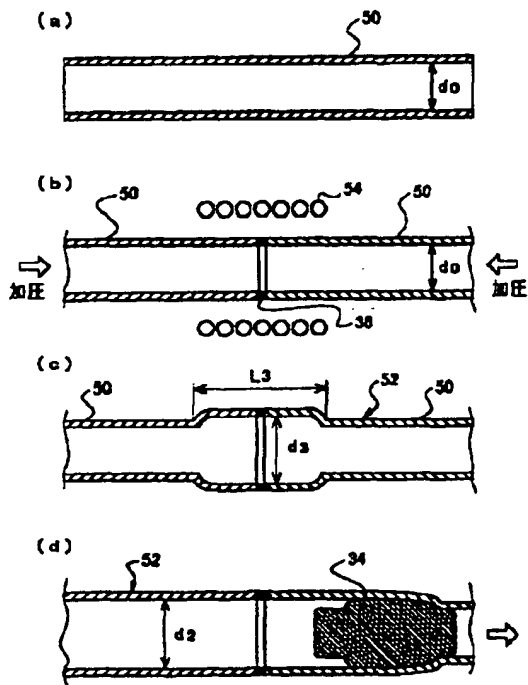
【図4】



【図7】



【図5】



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(72)発明者 稲垣 繁幸

愛知県名古屋市南区天白町3-9-111

大同特殊鋼天白荘205

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DA00 DA09 DA13 DB02 DC03

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(71) Applicant: 000003713  
Daido Steel Company, Incorporated  
1-11-18 Nishiki, Naka-ku, Nagoya-shi, Aichi-ken

(72) Inventor: Sueo Hiyamizu  
501 Yagoto Sun Heights, 2-311 Omoteyama, Tenpaku-ku, Nagoya-shi,  
Aichi-ken

(72) Inventor: [Hakuji] Horio  
18 Minami-Shikamochi, Kagiya-cho, Toukai-shi, Aichi-ken  
Daido Steel, Chita Dormitory C-317

(72) Inventor: Kazushige [Kiaki]  
2-38 [illegible], Midori-ku, Nagoya-shi, Aichi-ken

(74) Agent: 100095669  
Patent Attorney Noboru Ueno (1 Outside Individual)

Continued on the last page

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(54) Title of the Invention: Metal Pipe Joint for Pipe Expansion and the Manufacturing Method Thereof

(57) Summary

(Problem)

Provide a metal pipe joint for pipe expansion and its manufacturing method, wherein even in the case of pipe expansion, (a) there is no decrease in the strength or the airtightness of the junction, (b) there is little deformation resistance at the time of pipe expansion, and (c) it is possible to reduce the level differences that occur in the junction.

(Means for Solving the Problem)

Obtain metal pipe joints 32 and 52 in which the internal diameters of the junctions are greater than the internal diameters of the non-conjugative regions, by either (a) diffusion bonding or welding to one another metal pipes 30 whose internal diameters in the vicinity of the ends have been expanded such that the end diameter expansion rate is greater than 5%, or (b) diffusing bonding metal pipe 50, whose internal diameter in the vicinity of the end has not been expanded, such that it reaches a prescribed lateral expansion rate.

Furthermore, obtain metal pipe joint 42 in which the internal diameter of the junction is greater than the internal diameter of the non-conjugative regions by mechanically fastening to one another metal pipes 40 whose internal diameters toward the ends have been expanded such that the end diameter expansion rate is greater than 10%.

[see source for drawings]

(c)

Machine work

Machine work

(Scope of Patent Claims)

(Claim 1)

A metal pipe joint for pipe expansion comprised of a plurality of bonded metal pipes, wherein the internal diameter of the junction is greater than the internal diameter of the non-conjugative regions.

(Claim 2)

A manufacturing method for a metal pipe joint for pipe expansion in which the internal diameter in the vicinity of the end of the metal pipe is expanded and said metal pipes are bonded to one another.

(Claim 3)

The manufacturing method for a metal pipe joint for pipe expansion according to Claim 2 in which the internal diameter in the vicinity of the end of said metal pipe is expanded such that the end diameter expansion rate is greater than 5%.

(Claim 4)

The manufacturing method for a metal pipe joint for pipe expansion according to either Claim 2 or Claim 3 in which the bonding method is a diffusion bonding method.

(Claim 5)

The manufacturing method for a metal pipe joint for pipe expansion according to either Claim 2 or Claim 3 in which the bonding method is an arc welding method.

(Claim 6)

A manufacturing method for a metal pipe joint for pipe expansion in which the internal diameter in the vicinity of the end of the metal pipe is expanded, thread is formed on the end of said metal pipe, and said metal pipes are mechanically fastened to one another with said thread.

(Claim 7)

The manufacturing method for a metal pipe joint for pipe expansion according to Claim 6 in which the internal diameter in the vicinity of the end of said metal pipe is expanded such that the end diameter expansion rate is greater than 10%.

(Claim 8)

A manufacturing method for a metal pipe joint for pipe expansion in which metal pipes whose internal diameters in the vicinity of the ends have not been expanded are butted, and are diffusion bonded under bonding conditions such that the junction vicinity laterally expands.

(Claim 9)

The metal pipe joint for pipe expansion according to Claim 8 that is diffusion bonded such that the lateral expansion rate of the junction vicinity is greater than 1.04.

(Detailed Description of the Invention)

(0001)

(Technical Field of the Invention)

The present invention is related to a metal pipe joint for pipe expansion and the manufacturing method thereof; more specifically, it is related to an ideal metal pipe joint for pipe expansion and its manufacturing method used for the plumbing for plants or line piping that is used in the chemical industry or the petrochemical industry, or as the oil well pipe of casing tubes, production tubes, or coiled tubes used in oil wells.

(0002)

(Prior Art)

Conventionally, in fields such as the chemical industry and the petrochemical industry, long metal pipes are used in order to transport corrosive liquids over long distances. For example, pipe lines are for the purpose of transporting crude oil obtained from an oil field to an oil refinery, for example, and their lengths span across tens of kilometers.

(0003)

Furthermore, when digging an oil well, in order to preserve the gallery that was excavated beneath the ground or to prevent crude oil leakage, steel pipes called casing are buried within the gallery. The oil field is normally in a location several thousand meters under ground, so it is necessary that the casing also have the length of several thousand meters.

(0004)

Moreover, seamless steel pipes that are superior with respect to corrosion resistance are generally used for metal pipes that are exposed to a corrosive environment, but the length of industrially mass produced seamless steel pipes is between 10 - 15 m, and the upper limit on the possible manufactured length is approximately 100 m. Accordingly, joints that connect multiple seamless steel pipes of length between 10 - 15 m are used in line piping or oil well pipe such as casing.

(0005)

As a bonding method for metal pipe that is used in such applications, threaded connection methods (mechanical coupling method), welding methods (orbital welding method), and diffusion bonding methods are well known.

(0006)

Furthermore, as for the joints (called "metal pipe joints" hereafter) in which multiple metal pipes that have prescribed length are united, it is typical for them to be used as they are, without expanding or reducing the internal diameter. In other words, it is typical for metal pipe joints that have a desired internal diameter to be manufactured by bonding metal pipes that have a desired internal diameter.

(0007)

However, in contrast to line piping that is laid above ground, casing that is used in oil wells is buried beneath the ground, so there are the following problems in using metal pipe joints that have prescribed internal diameters as casings without modification.

(0008)

Stated simply, it is difficult to excavate a bare gallery towards an oil field that is in a location several thousand meters under ground. Therefore, oil well excavation operations sequentially repeat the following operations: (a) the operation of excavating a gallery using a drill pipe that has a bit that is mounted on its tip, (b) the operation of burying casing at a location in which digging has advanced to a certain extent in order to protect the gallery, and (c) the operation of pouring cement between the buried casing and the stratum, and stabilizing the casing. As a result, oil wells have a structure in which multiple casing is overlapped in a nested form.

(0009)

The structure of a typical oil well is shown in Figure 6. Oil well 10 that is illustrated in Figure 6 is equipped with conductor pipe 12 that has a maximum external diameter for the purpose of protecting the gallery wall in the vicinity of the surface of the earth, surface casing 14 that is sequentially inserted in a nested form into conductor pipe 12, intermediate casing 16, and four production casings 18 of maximum length that reach oil stratum 20.

(0010)

However, when burying the next casing (called "inner side casing" hereafter) inside the gallery through the hole in the center of the casing that was previously buried (called "outer side casing" hereafter), there are cases in which the insertion of the inner side casing becomes difficult because the axis of the inner side casing and the axis of the outer side casing shift out of alignment, or the shape of either the inner side

casing or the outer side casing is irregular. Therefore, it was necessary to make the external diameter of the inner side casing approximately 10 - 30% smaller than the internal diameter of the outer side casing to be on the safe side.

(0011)

Furthermore, the production efficiency of the oil well is dependant on the internal diameter of the production casing that reaches the oil stratum.

(3) Japanese Unexamined Patent Application 2000-107870

Accordingly, in order to secure prescribed production efficiency, it is necessary not only to give the internal diameter of the production casing a prescribed size, but also to enlarge the internal diameter of the casing that was previously buried. Therefore, the necessity to enlarge the internal diameter of the gallery that is excavated in the vicinity of the surface of the earth arose, and became a factor that increases the cost of oil well drilling.

(0012)

Thereby, in order to solve this problem, a method was disclosed in Published Japanese Translation of a PCT Application H7-507610 that expands the casing in the radial direction with respect to the borehole by burying casing made from malleable materials in the borehole that was excavated under the earth, and expanding a hydraulic expanding tool within the casing.

(0013)

Furthermore, a method was disclosed in International Publication Number WO98/0062 that inserts steel pipe made from a malleable type of metal, which generates strain hardening, into either a gallery or casing that was previously buried without incidence of necking or ductile fracture, and expands casing using a mandrel that has a tapered surface made of a nonmetal material.

(0014)

Through the methods disclosed in Published Japanese Translation of a PCT Application H7-507610 or International Publication Number WO98/0062, it is possible to insert inner side casing that has a relatively small external diameter in comparison to the gallery or outer side casing internal diameter, so there is the advantage that it is possible to smoothly perform the inner side casing insertion operation.

(0015)

Moreover, the expansion of inner side casing that was inserted into a gallery of outer side casing is performed using a hydraulic expansion tool or a mandrel, so there is the advantage that nearly the entire cross sectional area of the gallery can be used for crude oil transportation. Furthermore, because the effective cross sectional area of the gallery becomes large, there is the advantage that it is possible to reduce the internal diameter of the gallery to be excavated, and it is thus possible to cut excavation costs.

(0016)

Furthermore, as disclosed in Published Japanese Translation of a PCT Application H7-507610, in the case in which casing is expanded in the radial direction with respect to the borehole, the casing is maintained by the compressive stress received from the borehole wall, so there is the advantage that the cementing operation becomes unnecessary.

(0017)

(Problems Addressed by the Invention)

However, the entire length of casing that is used in oil wells reaches several thousand meters, so although junctions must necessarily be present, junctions are not taken into consideration in either Published Japanese Translation of a PCT Application H7-507610 or International Publication Number WO98/0062.

(0018)

For example, in the case in which metal pipes are bonded through welding methods or metallurgical bonding methods such as diffusion bonding to form metal pipe joints, heat-affected zones generate at the time of bonding in the vicinity of the junctions, so there are cases in which the deformability decreases. Therefore, in the case in which the obtained metal pipe joints are expanded as they are using a mandrel, for example, there is the problem in which there is a danger that fissures will generate in the junctions.

(0019)

Moreover, in the case in which metal pipe is bonded through a threaded connection method to form a metal pipe joint and this is expanded with a mandrel, for example, there is the problem that the thread portion

becomes loose due to plastic-deformation at the time of expansion and the airtightness of the junction decreases.

(0020)

Furthermore, the threaded connection method normally forms outer thread 1a and 2b on the ends of metal pipes 1 and 2 as shown in Figure 7, and unites metal pipes 1 and 2 through coupling 7 that has internal thread 7a that can screw into this external thread 1a and 2b. Accordingly, the vicinity of the junction becomes more thick-walled than the non-conjugative regions, so in the case in which such a metal pipe joint is expanded using a mandrel, for example, there is the problem in which the deformation resistance of the junction becomes large and the expansion operation cannot be performed smoothly.

(0021)

Moreover, in the case in which a metal pipe joint with length of several thousand meters that has a uniform internal diameter is expanded at once using a mandrel, the mandrel constantly receives a reactive force from the metal pipe joint at the time of the pipe expansion, so a large motive energy becomes necessary to move the mandrel.

(0022)

In order to solve this problem, a point is disclosed in International Publication Number WO98/0062, for example, in which the frictional force that generates between the mandrel and the casing is reduced by constructing the tapered surface of the mandrel with a nonmetal material such as zirconia, but there is no change in the fact that the mandrel continuously receives a constant reactive force from the casing during pipe expansion, and it is insufficient with respect to motive energy conservation.

(0023)

Furthermore, as disclosed in Published Japanese Translation of a PCT Application H7-507610, it is possible to conserve motive energy in comparison to the case in which the mandrel is expanded all at once by repeating the following process: retain the hydraulic expansion tool in a location within the casing, expand the hydraulic expansion tool and expand only the casing that is in that position, and then move it to the upper region after contracting the hydraulic tool. However, this results in expanding the casing in a multistage manner, so there is the drawback that the operation efficiency is poor.

(0024)

Moreover, in the case in which the metal pipe is bonded using a diffusion bonding method, it is typical to evenly process only the end face of the metal pipe and use it for bonding without adjusting the periphery surface and the wall thickness. However, in industrially mass produced metal pipes, there is a prescribed dimensional tolerance, and the external diameters and wall thickness of each metal pipe vary within the range of the dimensional tolerance.

(0025)

Therefore, in the case in which mass produced metal pipes are used as they are in diffusion bonding, there is the danger that level differences will arise in the junctions of the metal pipe joints that are obtained. Stress tends to concentrate in level differences that generate in the junctions, so in the case in which such metal pipe joints are expanded, there is the danger that fissures will generate from the regions of level differences. Furthermore, because the level differences remain in the junctions even after pipe expansion, there is the danger that fatigue characteristics and corrosion resistance will diminish due to stress concentration or the retention of corrosive substances. However, nothing is disclosed in the aforementioned prior art literature regarding specific means to solving such problems.

(0026)

A problem addressed by the present invention is to provide a metal pipe joint for pipe expansion and its manufacturing method in which (a) fissures do not generate in the junction, even if pipe expansion is performed, and (b) there is no reduction in the airtightness of the junction that originates from the loosening of thread.

(0027)

Furthermore, another problem addressed by the present invention is to provide a metal pipe joint for pipe expansion and its manufacturing method, in which (a) the deformation resistance at the time of pipe expansion is small and (b) motive energy conservation in the pipe expansion operation is possible.

(0028)

Furthermore, another problem addressed by the present invention is to provide a metal pipe joint for pipe expansion and its manufacturing method, in which (a) the level differences that arise in the junctions are small, and (b) is superior with respect to strength, fatigue characteristics, and corrosion resistance.

(0029)

(Means for Solving the Problems)

In order to solve the aforementioned problems, the metal pipe joint for pipe expansion of the present invention can be summarized in that it is a metal pipe joint in which multiple metal pipes have been bonded, and the internal diameters of the junctions are larger than the internal diameters of the non-conjugative regions.

(0030)

Specifically, such a metal pipe joint for pipe expansion can be easily manufactured by expanding the internal diameter of the vicinity of the end of the metal pipe in advance, and then bonding like metal pipes to one another. In this case, it is desirable to expand the internal diameter of the vicinity of the end of the metal pipe such that the end diameter expansion rate is greater than 5%. If the end diameter expansion rate is less than 5%, then there is the danger that fissures will generate from the junctions when performing pipe expansion, so this is undesirable. Moreover, in this case, a diffusion bonding method or an arc welding method would be ideal as a bonding method.

(0031)

Moreover, a metal pipe joint such as that described above can also be manufactured by expanding the internal diameter in the vicinity of the end of the metal pipe, forming thread on the end of the metal pipe, and mechanically fastening like metal pipes to one another with the thread. In this case, it is desirable to expand the internal diameter of the vicinity of the end of the metal pipe such that the end diameter expansion rate is greater than 10%. If the end diameter expansion rate is less than 10%, the thread regions plastic-deform and the airtightness of the thread regions decreases, so this is undesirable.

(0032)

Furthermore, a metal pipe joint such as that described above can also be manufactured by butting metal pipes whose internal diameters in the vicinity of the end have not been expanded, and diffusion bonding them under bonding conditions such that the junction vicinity laterally expands. In this case, it is desirable to perform diffusion bonding such that the lateral expansion rate in the junction vicinity is greater than 1.04%. If the lateral expansion rate is less than 1.04%, there is the danger that fissures will generate from the junctions when performing pipe expansion, so this is undesirable.

(0033)

As for the metal pipe joint for pipe expansion of the present invention that has the configuration described above, the internal diameters of the junctions are larger than the internal diameters of the non-conjugative regions, so in the case in which such a metal pipe joint for pipe expansion is expanded using a mandrel, for example, it is possible to restrain the plastic stress of the junctions such that it is less than the plastic stress of the non-conjugative regions.

(0034)

Therefore, it becomes difficult for fissures to generate in the junctions due to pipe expansion, even in the case in which, for example, when metal pipe whose end internal diameters have been expanded at a prescribed end diameter expansion rate are bonded through diffusion bonding or welding methods and the obtained metal pipe joint is expanded, heat-affected zones generate in the vicinity of the bonding boundaries and the deformability in the vicinity of the bonding boundaries is diminished.

(0035)

Moreover, if metal pipes whose end internal diameters have not been expanded are butted, a metal pipe joint is formed by plastic-deforming the junction into a barrel shape at a prescribed lateral expansion rate with the pressure at the time of diffusion bonding, and this is expanded; then not only is the generation of fissures in the junction restrained, but there is also the advantage that the process of expanding the end internal diameters of the metal pipes becomes unnecessary.

(0036)

Furthermore, in the case in which a metal pipe joint is formed by using a threaded connection method to bond metal pipes whose end internal diameters have been expanded at a prescribed end diameter expansion rate, if the metal pipe joint is expanded such that the pipe expansion rate is less than the end diameter expansion rate, then there is to be no incidence of plastic-deformation of the junction. Therefore, there is no decrease in airtightness, which originates from the loosening of thread.

(0037)

Moreover, in the metal pipe joint for pipe expansion of the present invention, the internal diameters in the junction vicinity are greater than the internal diameters of the non-conjugative regions, so the deformation resistance in the junction vicinity becomes small. Therefore, it is possible to perform the pipe expansion operation smoothly, and the motive energy in the pipe expansion operation is also conserved.

(0038)

Furthermore, in the case in which a metal pipe joint is formed by expanding the ends of the metal pipes at a prescribed end diameter expansion rate in advance and bonding the expanded metal pipes, it is possible to at least align each of the metal pipes through diameter expansion. Therefore, even in the case in which a metal pipe joint is manufactured using metal pipes in which the external diameters or wall thicknesses vary within a prescribed dimensional tolerance, it is possible to reduce the level differences that generate on the inside surface of the junction, and it becomes possible to obtain a metal pipe junction that is superior with respect to strength, fatigue characteristics, and corrosion resistance.

(0039)

(Embodiments of the Invention)

Embodiments of the present invention will be explained in detail below with reference to the drawings.

Figure 1 is a flow chart that shows manufacturing method (called "method A" hereafter) for the metal pipe joint for pipe expansion of the first embodiment of the present invention. In Figure 1, method A comprises a diameter expansion process, an end face finishing process, and a diffusion bonding process.

(0040)

First, the diameter expansion process will be explained. The diameter expansion process in which only the internal diameters of both ends inside cylindrical metal pipe 30 as shown in Figure 1 (a) are enlarged using an appropriate industrial tool, and metal pipe 30, in which the internal diameter  $d_1$  of the end has become greater than the internal diameter  $d_0$  in the center, is processed as shown in Figure 1 (b).

(0041)

Here, as for the metal pipe 30 that is used in the present invention, there are no particular restrictions regarding material quality or dimensions as long as it is of a material that has deformability that can withstand the pipe expansion described later. For example, in metal pipe joints that are used in applications in which only mechanical characteristics are required, it is possible to use carbon steel for metal pipe 30.

Moreover, in applications in which both strength and corrosion resistance of line pipes or oil well pipes are required, for example, it is possible to use stainless steels such as martensitic stainless steel, two-phase stainless steel, or austenitic stainless steel, or Ti alloy.

(0042)

Moreover, in the present invention, the increment of the internal diameter of metal pipe 30 after expansion with respect to the minimum value of the internal diameter of each metal pipe 30 prior to expansion is called the end diameter expansion rate, and it is defined by the following Formula 1.

(0043)

(Formula 1)

End diameter expansion rate (%) =  $(d_1 - d_{0 \min}) \times 100 / d_{0 \min}$ .

Where:

$d_1$ : internal diameter of the end of metal pipe 30 after expansion

$d_{0 \min}$ : minimum value of the internal diameter of the end of metal pipe 30 prior to expansion

(0044)

In the case of method A, it is desirable for the end diameter expansion rate to be greater than 5%. If the end diameter expansion rate is less than 5%, then the necessity to greatly plastic-deform the junctions arises in the pipe expansion process explained later, and there is the danger that fissures will generate in the junctions, so this is undesirable. Moreover, if the end diameter expansion rate is less than 5%, there are cases in which large level differences generate in the junctions due to the dimensional accuracy of each metal pipe 30, and the fatigue strength diminishes, so this is also undesirable.

(0045)

This is because, if the end diameter expansion rate is less than 5% in the case in which the internal diameter of metal pipe 30 varies within a prescribed dimensional tolerance, there is the danger that only metal pipes whose internal diameter  $d_0$  prior to expansion is smaller than the internal diameter  $d_1$  after expansion will be expanded, and metal pipes that have internal diameters greater than  $d_1$  will not be expanded.

(0046)

Also, as the minimum value  $d_{0 \min}$  of the internal diameter that is used to calculate the end diameter expansion rate, from the perspective of allowing for safety it is desirable to use the minimum value anticipated from the specifications of the metal pipe used in bonding, but it would also be acceptable to use an actual measurement.

(0047)

Moreover, from the perspective of reducing plastic-deformation in the junctions and restraining the generation of fissures, the larger the end diameter expansion rate is the better. Therefore, in accordance with the simplicity of the processing of metal pipe 30 and the applications of the metal pipe joint that is obtained, diameter expansion should be performed with the ideal end diameter expansion rate within a range below the pipe expansion rate described later.

(0048)

Moreover, the length (called "diameter expansion length" hereafter, represented by " $L_1$ " within Figure 1 (b)) of the portion in which the internal diameter was enlarged through diameter expansion may be arbitrarily chosen with consideration on the simplicity of processing of metal pipe 30 and the applications, but from the perspective of reducing deformation resistance in the pipe expansion process described later and conserving motive energy in the pipe expansion operation, the longer it is the better.

(0049)

Furthermore, there are no particular restrictions on the diameter expansion method either, and it is possible to use various methods. Normally, a mandrel or a plug that has an external diameter corresponding to  $d_1$

that is expressed in Formula 1 should be inserted into the end of metal pipe 30 up to a prescribed length, and the end internal diameter should then be expanded.

(0050)

Next, the end face finishing process will be explained. The end face finishing process is a process in which, as shown in Figure 1 (c), the end face of metal tube 30, whose end internal diameter was expanded through the diameter expansion process, is machine finished to a prescribed surface roughness. This is because, if the surface texture of the end face of metal pipe 30 is rough, then the bonding boundaries will not sufficiently adhere and high bond strength will not be obtained in the diffusion bonding process described later.

(0051)

Also, there are no particular restrictions regarding the end surface finishing method, and various methods such as grinding or lapping can be used. Moreover, in the case in which the surface roughness of the end face of metal pipe 30 is held within a prescribed range even after diameter expansion, the end face finishing process is not absolutely necessary, and it can be omitted.

(0052)

Next, the diffusion bonding process will be explained. The diffusion bonding process is a process in which metal pipes 30, whose end internal diameters were expanded in the diameter expansion process and whose end faces were finished to a prescribed surface roughness in the end face finishing process, are butted and like metal pipes 30 are diffusion bonded to one another.

(0053)

Here, as for the diffusion bonding method, there is (a) solid phase diffusion bonding that directly butts metal pipes 30 and diffuses elements while maintaining them in the solid phase, and (b) liquid phase diffusion bonding that places an insert material onto the bonding boundary and diffuses elements while temporarily melting the insert material, and either method may be used.

(0054)

In particular, with liquid phase diffusion bonding, joints that have strength that is equivalent to that of the parent material can be obtained in a short period of time in comparison to solid phase diffusion bonding, so it is ideal as a bonding method. One example of metal pipe joint 32 that is bonded through liquid phase diffusion bonding by placing insert material 36 on the bonding boundary of metal pipes 30 and 30 is shown in Figure 1 (d).

(0055)

Moreover, as for the conditions for diffusion bonding, an ideal range should be chosen according to the material of the metal pipe 30 that is used. Specifically, it should be performed under the following conditions.

(0056)

First, it is preferable for the surface roughness  $R_{max}$  of the bonding surface to be less than  $50\text{ }\mu\text{m}$ . If the surface roughness  $R_{max}$  of the bonding surface exceeds  $50\text{ }\mu\text{m}$ , like metal pipes 30 will not sufficiently adhere at the bonding surface and high bonding strength will not be obtained, so this is not desirable. From the perspective of obtaining high bonding strength, the smaller the surface roughness  $R_{max}$  is the better.

(0057)

Moreover, as for the insert material 36 that is used, a Ni-family alloy or Fe-family alloy that has a melting point that is less than  $1200^{\circ}\text{C}$  is ideal. If the melting point of insert material 36 exceeds  $1200^{\circ}\text{C}$ , a high bonding temperature will become necessary, which is undesirable because the parent material will be melted during bonding, or unbonded portions will generate because insert material 36 is not melted.

(0058)

Furthermore, the thickness of the insert material 36 that is used is preferably less than 100  $\mu\text{m}$ . If the thickness of the insert material 36 exceeds 100  $\mu\text{m}$ , the diffusion of elements at the bonding boundary will not be sufficiently performed and the bonding strength will diminish, so this is undesirable.

(0059)

Also, there are no particular restrictions regarding the shape of insert material 36,

and an insert material 36 made of foil with thickness less than 100  $\mu\text{m}$  may be placed on the bonding boundary. Alternatively, it would also be acceptable to disseminate a powder or squamation insert material 36 on the bonding boundary, or to make it into a paste and apply it to the bonding boundary in order to bring the thickness to less than 100  $\mu\text{m}$ .

(0060)

A non-oxidizing atmosphere is preferable for the bonding atmosphere. If bonding is conducted under an oxidizing atmosphere, the bonding boundary vicinity will oxidize and the bonding strength will diminish, so this is undesirable.

(0061)

It is ideal for the bonding temperature to be within a range that is greater than 1250°C and less than 1400°C. If the bonding temperature is less than 1250°C, portions of insert material 36 will not melt, or the diffusion of elements will not be conducted sufficiently, causing the bonding strength to diminish, so this is undesirable. Moreover, if the bonding temperature is greater than 1400°C, there is the danger that the parent material will melt, so this is not desirable.

(0062)

It is ideal for the retention time of the bonding temperature to be greater than 30 seconds and less than 300 seconds. If the retention time is less than 30 seconds, the diffusion of elements on the bonding boundary will become insufficient and the bonding strength will diminish, so this is undesirable. Moreover, the operation efficiency will diminish if the retention time is greater than 300 seconds, so this is also undesirable.

(0063)

Furthermore, it is ideal for the pressure that is applied to the bonding boundary to be greater than 1.5 MPa and less than 5 MPa. If the applied pressure is less than 1.5 MPa, the adherence of the bonding boundary will become insufficient and the bonding strength will diminish, so this is undesirable.

(0064)

Moreover, in method A, pipe expansion of the metal pipe joint is performed in the pipe expansion process described later after the metal pipes are bonded, so it would be acceptable for the junction vicinity to slightly deform after bonding. However, if the sum of the increment of the internal diameter in the diameter expansion process and the increment of the internal diameter that originates from deformation at the time of bonding exceeds the pipe expansion rate in the pipe expansion process described later, then irregularities will remain in the vicinity of the bonding boundary even after pipe expansion, which becomes a cause for the reduction of bonding strength. Accordingly, in method A, it is ideal to configure the applied pressure to less than 5 MPa such that the junction vicinity does not excessively deform.

(0065)

Moreover, as a heating method when performing diffusion bonding, it is possible to use various methods such as high frequency induction heating, high frequency direct conduction heating, or resistance heating. Among these, with high frequency induction heating and high frequency direct conduction heating, it is possible to easily heat even with a relatively large material to be bonded, the heating efficiency is high, and it is possible to heat to the bonding temperature in an extremely short amount of time, so they are particularly suitable as heating methods.

(0066)

However, as for the high frequency current that is used in high frequency induction heating or high frequency direct conduction heating, it is ideal to use a current that has frequency less than 100 kHz. If the frequency exceeds 100 kHz, only the surface will be heated due to the skin effect and the entire bonding surface will not be heated uniformly, so this is undesirable.

(0067)

Next, the pipe expansion process for the metal pipe joint for pipe expansion that was obtained in this way will be explained. The pipe expansion process is a process in which pipe expansion is performed on the metal pipe joint 32 that was manufactured in the diameter expansion process, end face finishing process, and the diffusion bonding process described above, and the internal diameter of metal pipe joint 32 is set to a uniform size.

(0068)

Specifically, mandrel 34 is inserted as shown in Figure 2 (a) from one end of metal pipe joint 32 whose internal diameters of the junctions and non-conjugative regions are respectively  $d_1$  and  $d_0$ , mandrel 34 is moved towards the other end of metal pipe joint 32 as shown in Figure 2 (b), and the internal diameter of metal pipe joint 32 is enlarged to  $d_2$ . In the present invention, the increment of the internal diameter after pipe expansion with respect to the minimum value of the internal diameter of the non-conjugative regions prior to pipe expansion is called the pipe expansion rate, and it is defined by the following Formula 2.

(0069)

(Formula 2)

Pipe expansion rate (%) =  $(d_2 - d_{0 \min}) \times 100 / d_{0 \min}$

Where:

$d_2$ : internal diameters of the non-conjugative regions after pipe expansion

$d_{0 \min}$ : minimum value of the internal diameters of the non-conjugative regions prior to pipe expansion

(0070)

Also, in the case of method A, the pipe expansion rate may be arbitrarily chosen with consideration on the deformability of metal pipe 30 and the application of metal pipe joint 32. Moreover, if the bonding conditions are appropriate, it is possible to highly maintain the deformability of the junction vicinity, so it is also possible to expand with a pipe expansion rate that is larger than the end diameter expansion rate. Furthermore, it would be acceptable to use the minimum expected value from the specifications as the minimum value  $d_{0 \min}$  of the internal diameter of the non-conjugative regions prior to pipe expansion, and the fact that an actual measurement may also be used is the same as for Formula 1.

(0071)

Next, the effects of method A will be explained. If the diameters of the ends of metal pipes 30 (Figure 1 (a)) that have prescribed length and internal diameter are expanded with a prescribed end diameter expansion rate and a prescribed diameter expansion length  $L_1$  (Figure 1 (b)), and like metal pipes 30 are diffusion bonded to one another after the end faces are machine finished to a prescribed surface roughness (Figure 1 (c)), then it is possible to obtain metal pipe joint 32 in which the internal diameters  $d_1$  of the junctions have become larger than the internal diameters  $d_0$  of the non-conjugative regions as shown in Figure 1 (d).

(0072)

If mandrel 34 is inserted into one end of such a metal pipe joint 32 and mandrel 34 is moved towards the other end, then the internal diameter of metal pipe joint 32 enlarges, and it is possible to obtain metal pipe joint 32 that has a constant internal diameter  $d_2$  as shown in Figure 2 (b).

(0073)

At this time, the internal diameter  $d_1$  of the junction prior to pipe expansion has become greater than the internal diameters  $d_0$  of the non-conjugative regions, so the plastic stress of the junction at the time of pipe expansion becomes smaller than the plastic stress of the non-conjugative regions. Therefore, it becomes difficult for fissures to generate in the junction due to pipe expansion, even in the case in which heat-affected zones generate at the time of diffusion bonding and the deformability of the junction diminishes.

(0074)

Moreover, because the internal diameter  $d_1$  of the junction is larger than the internal diameter  $d_0$  of non-conjugative regions, the deformation resistance in the junction vicinity becomes small. The quantity of diminution becomes larger as the internal diameter  $d_1$  of the junction becomes larger or the diameter expansion length  $L_1$  becomes longer. Therefore, the sum of the frictional resistance that mandrel 34

receives at the time of pipe expansion becomes small in comparison to the case in which a metal pipe joint that has a uniform internal diameter is expanded, and motive energy is conserved in the pipe expansion operation.

(0075)

Furthermore, even in the case in which the exterior diameters and wall thicknesses of each metal pipe 30 vary within the dimensional tolerance, if the internal diameters in the end vicinity of metal pipes 30 are expanded and they are bonded after the internal diameters of all of the metal pipes 30 are aligned, then it is possible to reduce the level differences that generate on the inner periphery side of the junction of metal pipe joint 32. Therefore, with such a metal pipe joint 32, the danger that fissures that originate from level differences in the junction will generate is small, even if pipe expansion is performed. Moreover, stress concentration and the retention of corrosive substances become unlikely, so the strength, fatigue characteristics, and corrosion resistance of metal pipe joint 32 that was expanded will not diminish.

(0076)

Also, a diffusion bonding method is used as the bonding method in method A described above, but it would also be acceptable to use an arc welding method, and through this it would be possible to obtain the same results (called "method A" hereafter). In this case, the internal diameters of the end vicinity of metal pipes 30 are expanded with a prescribed end diameter expansion rate in the diameter expansion process, grooves are formed on metal pipes 30 in the end face finishing process, and these are butted and molten metal is clad in the grooves.

(0077)

Next, the manufacturing method of the metal pipe joint for pipe expansion of the second embodiment of the present invention will be explained. Figure 3 is a flow chart that shows the manufacturing method (called "method B" hereafter) of the metal pipe joint for pipe expansion of the second embodiment of the present invention. In Figure 3, method B comprises a diameter expansion process, a thread working process, and a fastening process.

(0078)

The diameter expansion process is a process in which, in the same manner as method A explained above, by enlarging only the internal diameter of the end vicinity within cylindrical metal pipe 40 as shown in Figure 3 (a) using an appropriate industrial tool, the metal pipe 40, in which the internal diameter of the end vicinity has been expanded at a prescribed end diameter expansion rate, is processed as shown in Figure 3 (b).

(0079)

However, in the case of method B, it is desirable for the end diameter expansion rate to be greater than 10%. If the end diameter expansion rate is less than 10%, the necessity to greatly plastic-deform the junctions in the pipe expansion process described later will arise, and if junctions that have been fastened through threaded connection methods are plastic-deformed, the thread will become loose and the airtightness will diminish, so this is undesirable.

(0080)

Also, (a) the fact that any material that has deformability that can withstand the pipe expansion can be used for metal pipe 40, (b) the fact that the expansion length  $L_1$  can be arbitrarily chosen with consideration on simplicity of processing of metal pipe 40, and (c) the fact that various methods can be used for the diameter expansion method are all the same as method A described above.

(0081)

Next, in the thread working process, external thread 40a is formed on the end of metal pipe 40 whose end internal diameter was expanded in the diameter expansion process, as shown in Figure 3 (c). Also, in the case of threaded connection methods, the load that can support the junctions is dependant upon the length  $L_2$  of the thread, so it is possible to arbitrarily establish thread length  $L_2$  according to the characteristics required by metal pipe joint 42.

(0082)

Next, the fastening process is a process in which like metal pipes 40, whose end internal diameters were expanded in the diameter expansion process and external thread 40a was established on the ends in the thread working process, are fastened to one another using coupling 44. Internal thread 44a that can screw into external thread 40a that was formed on metal pipes 40 is formed on coupling 44. Metal pipe joint 42 that was obtained in this way is shown in Figure 3 (d).

(0083)

The manufactured metal pipe joint 42 is expanded in the same manner as with metal pipe joint 32 that was obtained through method A, and the internal diameter of metal pipe joint 42 is enlarged to the uniform size  $d_2$ . Specifically, mandrel 34 is inserted from one end of metal pipe joint 42 as shown in Figure 4 (a), and the internal diameter of metal pipe joint 42 is expanded with a prescribed pipe expansion rate by moving mandrel 34 towards the other end of metal pipe joint 42, as shown in Figure 4 (b).

(0084)

Here, in the case of method B, it is desirable to perform the pipe expansion of metal pipe joint 42 with a pipe expansion rate that is less than the end diameter expansion rate of metal pipe 40. If the pipe expansion rate exceeds the end diameter expansion rate, there is the danger that the junction will plastic-deform and the threads will become loose at the time of pipe expansion, so this is undesirable. Moreover, the junction vicinity is thick-walled because there is the coupling 44. Therefore, expanding pipe with a pipe expansion rate that exceeds the end diameter expansion rate invites the increase of deformation resistance and a smooth pipe expansion operation becomes difficult, so this is undesirable.

(0085)

Next, the effects of method B will be explained. If the internal diameters of the end vicinity of metal pipes 40 are expanded in advance such that the end diameter expansion rate is greater than 10%, and like metal pipes 40 are bonded to one another through a threaded connection method, then it is possible to easily obtain metal pipe joint 42 in which the internal diameter  $d_1$  of the junction has become larger than the internal diameter  $d_0$  of the non-conjugative regions.

(0086)

If metal pipe joint 42 that was obtained in this way is expanded using a mandrel, for example, the deformation resistance of the junction vicinity becomes small in the same manner as with method A. Therefore, motive energy in the pipe expansion operation can be conserved in comparison to the case in which a metal pipe joint that has a uniform internal diameter is expanded. In addition, pipe expansion is performed with a pipe expansion rate that is less than the end diameter expansion rate, so the problem that is specific to threaded connection methods – the decrease of airtightness that originates in the thread plastic-deformation – is solved.

(0087)

Next, the manufacturing method of a metal pipe joint for pipe expansion of the third embodiment of the present invention will be explained. Figure 5 (a) - (c) is a flow chart that shows the manufacturing method of a metal pipe joint for pipe expansion of the third embodiment of the present invention (called "method C" hereafter).

(0088)

In the case of method C, the fact that any material that has deformability that can withstand the pipe expansion can be used for metal pipe 50 is the same as with method A. However, it differs from method A in that the ends of cylindrical metal pipes 50 are not expanded, but rather diffusion bonding is performed as they are, and the junction vicinity is deformed into a barrel shape at the time of diffusion bonding.

(0089)

Stated simply, the diameter of the end of cylindrical metal pipe 50 such as that shown in Figure 5 (a) is not expanded,

but instead they are butted and pressurized as they are (Figure 5 (b)), and the junction vicinity is heated through heat source 54. Also, as for the bonding method, a liquid phase diffusion bonding method that performs bonding by placing insert material 36 on the bonding boundary as shown in Figure 5 (b) may be used, or a solid phase diffusion bonding method that does not use insert material 36 may also be used.

(0090)

At this time, if the bonding conditions are appropriate, the bonding boundary vicinity is deformed into a barrel shape at the same time that diffusion bonding progresses on the bonding boundary, and it is possible to obtain metal pipe joint 52 in which the internal diameter  $d_{j3}$  of the junction has become larger than the internal diameter  $d_0$  of the non-conjugative regions as in Figure 5 (c). In the present invention, the increment of the internal diameter of the junction after diffusion bonding with respect to the minimum value of the internal diameter of the non-conjugative regions of the metal pipe is called the lateral expansion rate, and it is defined by the following Formula 3.

(0091)

(Formula 3)

Lateral expansion rate =  $d_3/d_{0 \min}$

Where:

$D_3$ : Internal diameter of the junction

$d_{0 \min}$ : Minimum value of the internal diameter of the non-conjugative regions

(0092)

In the case of method C, it is desirable for the lateral expansion rate to be greater than 1.04. If the lateral expansion rate is less than 1.04, there is the danger that the necessity to greatly plastic-deform the junction will arise in the pipe expansion process described later and fissures will generate in the junction, so this is undesirable.

(0093)

Also, it would be acceptable to use the minimum expected value from the specifications as the minimum value  $d_{0 \min}$  of the internal diameter of the non-conjugative regions, and the fact that an actual measurement may also be used is the same as for Formula 1. Moreover, from the perspective reducing the plastic stress of the junction at the time of pipe expansion and restricting the generation of fissures, the larger the lateral expansion rate is the better. Furthermore, from the perspective of making the deformation resistance small in the pipe expansion process, the longer the length (called the "expansion length" hereafter, expressed by " $L_3$ " within Figure 5 (c)) of the portion whose internal diameter was increased through diffusion bonding is the better.

(0094)

Moreover, in the case of method C, it is necessary to actively plastic-deform the bonding boundary vicinity at the time of diffusion bonding, so with regard to the diffusion bonding conditions, it is necessary to select conditions obtained from the required lateral expansion rate, for example. Specifically, bonding should be performed under the following conditions.

(0095)

Simply stated, it is ideal for the bonding temperature to be within a range that is greater than 1250°C and less than 1400°C. If the bonding temperature is less than 1250°C, portions of insert material 36 will not melt, or the diffusion of elements will not be conducted sufficiently, causing the bonding strength to diminish. Moreover, if the bonding temperature is too low, the deformation resistance of metal pipe 50 will become large and the prescribed lateral expansion rate will not be obtained, so this is undesirable. Furthermore, if the bonding temperature is greater than 1400°C, there is the danger that the parent material will melt, so this is also undesirable.

(0096)

It is ideal for the retention time of the bonding temperature to be greater than 60 seconds. If the retention time is less than 60 seconds, it will not be possible to obtain a large lateral expansion rate, so this is undesirable. Also, from the perspective of making the lateral expansion rate large, the longer the retention time is the better, so the retention time should be adjusted such that the prescribed lateral expansion rate is obtained.

(0097)

Moreover, it is ideal for the pressure that is applied to the bonding boundary to be greater than 2 MPa. If the applied pressure is less than 2 MPa, it will not be possible to obtain a large lateral expansion rate, so this is undesirable. Also, in the case of method C, from the perspective of making the lateral expansion rate large, the greater the applied pressure is the better, and it may even be greater than 5 MPa. However, if the lateral expansion rate exceeds the pipe expansion rate, irregularities will remain in the bonding boundary vicinity even after pipe expansion, and the bonding strength will diminish. Accordingly, it is desirable to adjust the applied pressure such that the lateral expansion rate is less than the pipe expansion rate.

(0098)

Furthermore, it is desirable for the heating width of the junction vicinity to be greater than 20 mm. If the heating width is less than 20 mm, the lateral expansion rate will become small and the expansion length  $L_3$  will become short, so this is undesirable. From the perspective of making the deformation resistance at the time of pipe expansion small, the larger the lateral expansion rate and the longer the expansion length  $L_3$  is the better, and therefore, it is better for the heating width to be long.

(0099)

Also, (a) the fact that it is desirable for the surface roughness  $R_{max}$  of the bonding surface to be less than  $50\text{ }\mu\text{m}$ , (b) the fact that a Ni-family alloy or an Fe-family alloy of thickness less than  $100\text{ }\mu\text{m}$  whose melting point is less than  $1200^\circ\text{C}$  is preferable, and (c) the fact that there are no particular restrictions with regard to the shaped of insert material, and it is possible to use a foil, a powder, or a squamation insert material are all the same as with method A.

(0100)

Moreover, (a) the fact that a non-oxidizing atmosphere is preferable for the bonding atmosphere, and (b) the fact that high frequency induction heating or high frequency direct conduction heating that uses a high frequency current with a frequency less than 100 kHz is preferable for the heat source when performing diffusion bonding are also both the same as with method A.

(0101)

Next, pipe expansion is performed on metal pipe joint 52 that was manufactured as described above and has a prescribed lateral expansion rate. Specifically, mandrel 34 is inserted from one end of metal pipe joint 52 as shown in Figure 5 (d), and mandrel 34 is then moved towards the other end of metal pipe joint 52.

(0102)

Also, (a) the fact that the pipe expansion rate may be arbitrarily chosen with consideration upon the deformability of metal pipe 50 and the application of metal pipe joint 52, and (b) the fact that it is possible to highly maintain the deformability of the junction vicinity if the bonding conditions are appropriate, so it is possible to perform pipe expansion with a pipe expansion rate that is greater than the end diameter expansion rate are both the same as with method A.

(0103)

Next, the effects of method C will be explained. If metal pipes 50 whose end internal diameters have not been expanded are butted, and the junction vicinity is actively plastic-deformed while like metal pipes 50 are diffusion bonded to one another, then it is possible to easily obtain metal pipe joint 52 in which the internal diameter  $d_3$  of the junction has become larger than the internal diameter  $d_0$  of the non-conjugative regions.

(0104)

If a metal pipe joint 52 that was obtained in this way is expanded using a mandrel for example, the deformation resistance of the junction vicinity becomes small in the same manner as with method A. Therefore, in comparison to the case in which a metal pipe joint that has a uniform internal diameter is expanded,

it is possible to perform the pipe expansion operation smoothly, and it is also possible to conserve motive energy in the pipe expansion operation.

(0105)

Moreover, because the internal diameter of the junction has become larger, it is possible to reduce the plastic stress of the junction at the time of pipe expansion. Therefore, as with method A, even in the case in which heat-affected regions generate in the junction vicinity and the deformability is diminished, the generation of fissures in the junction due to pipe expansion becomes unlikely, and it is possible to obtain a metal pipe joint that is superior with respect to strength and airtightness.

(0106)

(Embodiment 1)

Pipe expansion was performed on a metal pipe joint using method A. A carbon steel pipe made from American Petroleum Institution Grade H40 (this is notated as "API H40" hereafter) with an external diameter of 7 inches (178 mm) and wall thickness 0.231 inches (6 mm) was used for the metal pipe, and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 5%.

(0107)

Next, the end face of the expanded metal pipe was finished such that the surface roughness  $R_{max}$  is less than  $30\text{ }\mu\text{m}$ , a Ni-family alloy foil with melting point of  $1050^{\circ}\text{C}$  and thickness of  $50\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-3 was placed on the bonding boundary of the metal pipe, and liquid phase diffusion bonding was performed. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 25%.

(0108)

Also, a high frequency induction heating method that uses a high frequency current with a frequency of 3 kHz was used as the heating method for the junction. Moreover, the bonding conditions were such that the bonding temperature was  $1300^{\circ}\text{C}$ , the retention time was 180 seconds, and the applied pressure was 4 MPa, and bonding was performed in an Ar atmosphere.

(0109)

(Embodiments 2 - 3, Comparative Examples 1, 2)

Apart from respectively setting the end diameter expansion rates of metal pipes 30 to 0% (Comparative Example 1), 3% (Comparative Example 2), 20% (Embodiment 2), and 25% (Embodiment 3), the manufacturing and expansion of the metal pipe joints were performed in accordance with the same procedures as with Embodiment 1.

(0110)

With respect to the metal pipe joints that were obtained in Embodiments 1 - 3 and Comparative Examples 1 - 2, the maximum value of the level differences that generated on the inner periphery side of the junctions after bonding (this is simply called the "maximum level difference" hereafter) was measured. Moreover, a penetrant test was performed with respect to the junction surface after pipe expansion, and the presence of cracks was investigated. Furthermore, after the level differences alone that generated on the external periphery of the expanded joint were grinded with a grinder and set to less than 0.5 mm, an API 1104 specimen was extracted from this joint and tensile tests were conducted. The results are shown in Table 1.

(0111)

(Table 1)

[see source for numbers and English]

Test Number			Comparative Example 1	Comparative Example 2	Embodiment 1	Embodiment 2	Embodiment 3
Steel Pipe	Material						
	Dimensions	External Diameter (Inches)					
		Wall Thickness (Inches)					
End Diameter Expansion Rate (%)							
Bonding Surface Roughness (Rmax: $\mu\text{m}$ )							
Insert Material	Material						
	Melting Point ( $^{\circ}\text{C}$ )						
	Thickness ( $\mu\text{m}$ )						
	Form		Foil	Foil	Foil	Foil	Foil
Bonding Temperature ( $^{\circ}\text{C}$ )							
Retention Time (s)							
Applied Pressure (MPa)							
Bonding Atmosphere							
Heating Method for the Junction			High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)
Maximum Level Difference of the Junction (mm)							
Pipe Expansion Rate (%)							
Results of Junction Surface Penetrant Test			Cracks Present	Cracks Present	No Cracks	No Cracks	No Cracks
Tensile Test Results	Tensile Strength (MPa)						
	Break Location		Bonding Boundary	Bonding Boundary	Parent Material	Parent Material	Parent Material
Comprehensive Evaluation							

(0112)

In Comparative Example 1 in which the end diameter expansion rate was taken to be 0%, the maximum level difference reached 4 mm. Moreover, multiple fissures were recognized in the penetrant test after pipe expansion. Furthermore, the tensile strength exhibited low strength of 283 MPa, and the specimen broke away from the bonding boundary.

(0113)

In Comparative Example 2 in which the end diameter expansion rate was taken to be 3%, the maximum level difference fell to 1 mm. Moreover, significant fissures were recognized in the junction in the penetrant test after pipe expansion, but the number of fissures was less than in Comparative Example 1.

Accordingly, the tensile strength improved to 467 MPa, but the specimen broke away from the bonding boundary.

(0114)

In contrast to this, in Embodiments 1, 2, and 3 in which the end diameter expansion rates were respectively taken to be 5%, 20%, and 25%, the maximum level differences all fell to 0.5 mm. Moreover, no fissures were recognized on the bonding boundary in the penetrant tests following pipe expansion in any of the embodiments. Furthermore, the bonding strengths all exhibited strengths greater than 700 MPa, which is equivalent to that of the parent material, and the specimens broke away from the parent material side.

(0115)

From the above results, it became clear that if the end internal diameter of the metal pipe is expanded before the metal pipes are bonded such that a value greater than the prescribed end diameter expansion rate is achieved, it is possible to make the maximum level difference small. Moreover, it became clear that the greater the end diameter expansion rate is made, the more difficult it will be for fissures to generate in the junction at the time of pipe expansion, and a metal pipe joint with higher bonding strength can be obtained.

(0116)

(Embodiment 4)

Pipe expansion was performed on a metal pipe joint using method A. A carbon steel pipe made from API H40 with an external diameter of 7 inches (178 mm) and wall thickness 0.231 inches (6 mm) was used for the metal pipe, and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 15%.

(0117)

Next, the end face of the expanded metal pipe was finished such that the surface roughness  $R_{max}$  is less than  $30\text{ }\mu\text{m}$ , an Fe-3B-3Si-1C alloy foil with melting point of  $1200^{\circ}\text{C}$  and thickness of  $40\text{ }\mu\text{m}$  was placed on the bonding boundary of the metal pipe, and liquid phase diffusion bonding was performed. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 25%.

(0118)

Also, a high frequency induction heating method that uses a high frequency current with a frequency of 3 kHz was used as the heating method for the junction. Moreover, the bonding conditions were such that the bonding temperature was  $1250^{\circ}\text{C}$ , the retention time was 60 seconds, and the applied pressure was 4 MPa, and bonding was performed in an Ar atmosphere.

(0119)

(Embodiment 5)

A Ni-family alloy foil with a melting point of  $1140^{\circ}\text{C}$  and thickness of  $40\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was used as an insert material, and apart from retaining for 120 seconds at  $1300^{\circ}\text{C}$ , the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 4.

(0120)

(Embodiment 6)

A Ni-family alloy foil with a melting point of  $1140^{\circ}\text{C}$  and thickness of  $40\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was used as an insert material, and apart from setting the bonding temperature to  $1400^{\circ}\text{C}$  and the retention time to 300 seconds, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 4.

(0121)

(Comparative Example 3)

An Fe-2B-1Si alloy foil with a melting point of  $1290^{\circ}\text{C}$  and thickness of  $40\text{ }\mu\text{m}$  was used as an insert material, and apart from setting the bonding temperature to  $1400^{\circ}\text{C}$ , the retention time to 300 seconds, and the applied pressure to 5 MPa, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 4.

(0122)

With respect to the metal pipe joints that were obtained in Embodiments 4 - 6 and Comparative Example 3, maximum level difference tests, penetrant tests, and tensile tests were conducted in accordance with the same procedures as with Embodiment 1. The results are shown in Table 2.

(0123)

(Table 2)

[see source for numbers and English]

Test Number			Comparative Example 3	Embodiment 4	Embodiment 5	Embodiment 6
Steel Pipe	Material					
	Dimensions	External Diameter (Inches)				
		Wall Thickness (Inches)				
End Diameter Expansion Rate (%)						
Bonding Surface Roughness (Rmax: $\mu\text{m}$ )						
Insert Material	Material					
	Melting Point (°C)					
	Thickness ( $\mu\text{m}$ )					
	Form		Foil	Foil	Foil	Foil
Bonding Temperature (°C)						
Retention Time (s)						
Applied Pressure (MPa)						
Bonding Atmosphere						
Heating Method for the Junction			High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)
Maximum Level Difference of the Junction (mm)						
Pipe Expansion Rate (%)						
Results of Junction Surface Penetrant Test			Cracks Present	No Cracks	No Cracks	No Cracks
Tensile Test Results	Tensile Strength (MPa)					
	Break Location		Bonding Boundary	Parent Material	Parent Material	Parent Material
Comprehensive Evaluation						

(0124)

In Comparative Example 3 in which an insert material with a melting point of 1290°C was used, although the retention time was taken to be 300 seconds, fissures were recognized in the junction in the penetrant test following pipe expansion. Moreover, the tensile strength was 417 MPa and the specimen broke away from the bonding boundary. This is thought to have been because the diffusion of elements is not sufficiently performed on the bonding boundary because the melting point of the insert material is high, and thus the deformability of the bonding boundary vicinity is diminished.

(0125)

In contrast to this, in Embodiment 4 in which an insert material with a melting point of 1200°C was used, and in Embodiments 5 and 6 in which an insert material with a melting point of 1140°C was used, no fissures were recognized on the bonding boundary in the penetrant test following pipe expansion for any of the embodiments. Moreover, the bonding strengths all exhibited strengths greater than 700 MPa, which is equivalent to that of the parent material, and the specimens broke away from the parent material side.

(0126)

Also, all of the end diameter expansion rates of the metal pipes were taken to be 15% in Embodiments 3 - 6 and Comparative Example 3, so all of the maximum level differences were 0.5 mm.

(0127)

From the above results, it became clear that if an insert material with a melting point that is less than 1200°C is used in the case in which metal pipes are liquid phase diffusion bonded, then fissures will not generate on the junction following pipe expansion and metal pipe joints with high bond strength can be obtained.

(0128)

(Embodiment 7)

Pipe expansion was performed on a metal pipe joint using method A. A carbon steel pipe made from API H40 with an external diameter of 7 inches (178 mm) and wall thickness 0.231 inches (6 mm) was used for the metal pipe,

and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 15%.

(0129)

Next, the end face of the expanded metal pipe was finished such that the surface roughness  $R_{max}$  is less than  $30\text{ }\mu\text{m}$ , a squamation Ni-family alloy with a melting point of  $1140^{\circ}\text{C}$  that has a composition equivalent to JIS BNi-5 was placed on the bonding boundary of the metal pipe such that the thickness was  $100\text{ }\mu\text{m}$ , and liquid phase diffusion bonding was performed. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 25%.

(0130)

Also, a high frequency induction heating method that uses a high frequency current with a frequency of 3 kHz was used as the heating method for the junction. Moreover, the bonding conditions were such that the bonding temperature was  $1300^{\circ}\text{C}$ , the retention time was 180 seconds, and the applied pressure was 4 MPa, and bonding was performed in an Ar atmosphere.

(0131)

(Embodiment 8)

A Ni-family alloy powder that has a composition equivalent to JIS BNi-5 was used as an insert material, and this was placed on the bonding boundary of the metal pipe such that the thickness was  $30\text{ }\mu\text{m}$ . Apart from retaining for 60 seconds at the bonding temperature, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 7.

(0132)

(Embodiment 9)

A Ni-family alloy foil with thickness of  $40\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was used as an insert material, and apart from setting the bonding temperature to  $1250^{\circ}\text{C}$  and the retention time to 60 seconds, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 7.

(0133)

(Comparative Example 4)

A Ni-family alloy foil with thickness of  $200\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was used as an insert material, and apart from setting the bonding temperature to  $1400^{\circ}\text{C}$  and the retention time to 300 seconds, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 7.

(0134)

(Comparative Example 5)

A Ni-family alloy foil with thickness of  $40\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was used as an insert material, and apart from setting the bonding temperature to  $1450^{\circ}\text{C}$  and the retention time to 60 seconds, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 7.

(0135)

With respect to the metal pipe joints that were obtained in Embodiments 7 - 9 and Comparative Examples 4 - 5, maximum level difference tests, penetrant tests, and tensile tests were conducted in accordance with the same procedures as with Embodiment 1. The results are shown in Table 3.

(0136)

(Table 3)

[see source for numbers and English]

Test Number			Comparative Example 4	Embodiment 7	Embodiment 8	Embodiment 9	Comparative Example 5
Steel Pipe	Material						
	Dimensions	External Diameter (Inches)					
		Wall Thickness (Inches)					
End Diameter Expansion Rate (%)							
Bonding Surface Roughness (Rmax: $\mu\text{m}$ )							
Insert Material	Material						
	Melting Point ( $^{\circ}\text{C}$ )						
	Thickness ( $\mu\text{m}$ )						
	Form		Foil	Squamation	Powder	Foil	Foil
Bonding Temperature ( $^{\circ}\text{C}$ )							
Retention Time (s)							
Applied Pressure (MPa)							
Bonding Atmosphere							
Heating Method for the Junction			High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)
Maximum Level Difference of the Junction (mm)							
Pipe Expansion Rate (%)							
Results of Junction Surface Penetrant Test			Cracks Present	No Cracks	No Cracks	No Cracks	Cracks Present
Tensile Test Results	Tensile Strength (MPa)						
	Break Location		Bonding Boundary	Parent Material	Parent Material	Parent Material	Bonding Boundary
Comprehensive Evaluation							

(0137)

In Comparative Example 4 in which the thickness of the insert material was taken as 200  $\mu\text{m}$ , although the retention time was taken to be 300 seconds, fissures were recognized in the junction in the penetrant test following pipe expansion. Moreover, the tensile strength was 588 MPa, and the specimen broke away from the bonding boundary. This is thought to have been because the elements contained in the insert material were not sufficiently diffused because the insert material was thick, and thus the deformability of the bonding boundary vicinity was diminished.

(0138)

Moreover, in Comparative Example 5 in which the bonding temperature was taken as 1450°C, melting damage occurred in the junction vicinity. Also, fissures were recognized in the junction in the penetrant test following pipe expansion. Furthermore, the tensile strength was 657 MPa, and the specimen broke away from the bonding boundary.

(0139)

In contrast to this, in Embodiments 7, 8, and 9 in which the thickness of the insert material was set below 100  $\mu\text{m}$  and the bonding temperature was set below 1400°C, no melting damage was recognized in any of the junctions, and no fissures were recognized on the bonding boundary in the penetrant test following pipe expansion for any of the embodiments. Moreover, the bonding strengths all exhibited strengths greater than 700 MPa, which is equivalent to that of the parent material, and the specimens broke away from the parent material side.

(0140)

Also, all of the end diameter expansion rates of the metal pipes were taken to be 15% in Embodiments 7 - 9 and Comparative Examples 4 - 5, so all of the maximum level differences were 0.5 mm.

(0141)

From the above results, it became clear that if the width of the insert material is set to 100  $\mu\text{m}$  in the case in which metal pipes are liquid phase diffusion bonded, then fissures will not generate on the junction following pipe expansion and metal pipe joints with high bond strength can be obtained. Moreover, it also became clear that it is necessary to set the bonding temperature to less than 1400°C in order to suppress melting damage of the junction.

(0142)

(Embodiment 10)

Pipe expansion was performed on a metal pipe joint using method A. A carbon steel pipe made from API H40 with an external diameter of 7 inches (178 mm) and wall thickness 0.231 inches (6 mm) was used for the metal pipe, and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 15%.

(0143)

Next, the end face of the expanded metal pipe was finished such that the surface roughness  $R_{max}$  is less than  $30\text{ }\mu\text{m}$ , a Ni-family alloy foil with a melting point of  $1140^{\circ}\text{C}$  and thickness of  $40\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was placed on the bonding boundary of the metal pipe, and liquid phase diffusion bonding was performed. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 25%.

(0144)

Also, a high frequency induction heating method that uses a high frequency current with a frequency of 3 kHz was used as the heating method for the junction. Moreover, the bonding conditions were such that the bonding temperature was  $1400^{\circ}\text{C}$ , the retention time was 30 seconds, and the applied pressure was 5 MPa, and bonding was performed in an Ar atmosphere.

(0145)

(Embodiment 11)

Apart from setting the retention time at the bonding temperature to 300 seconds and the applied pressure to 1.5 MPa, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 10.

(0146)

(Comparative Example 6)

Apart from setting the retention time at the bonding temperature to 15 seconds, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 10.

(0147)

(Comparative Example 7)

A Ni-family alloy foil with thickness of  $30\text{ }\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was used as an insert material, and apart from setting the retention time at the bonding temperature to 300 seconds and the applied pressure to 1 MPa, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 10.

(0148)

(Comparative Example 8)

Apart from setting the bonding temperature to  $1250^{\circ}\text{C}$ , the retention time to 300 seconds, and the applied pressure to 7 MPa, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 10.

(0149)

With respect to the metal pipe joints that were obtained in Embodiments 10 - 11 and Comparative Examples 6 - 8, maximum level difference tests, penetrant tests, and tensile tests were conducted in accordance with the same procedures as with Embodiment 1. The results are shown in Table 4.

(0150)

(Table 4)

[see source for numbers and English]

Test Number			Comparative Example 6	Embodiment 10	Comparative Example 7	Embodiment 11	Comparative Example 8
Steel Pipe	Material						
	Dimensions	External Diameter (Inches)					
		Wall Thickness (Inches)					
End Diameter Expansion Rate (%)							
Bonding Surface Roughness (Rmax: $\mu\text{m}$ )							
Insert Material	Material						
	Melting Point ( $^{\circ}\text{C}$ )						
	Thickness ( $\mu\text{m}$ )						
	Form		Foil	Foil	Foil	Foil	Foil
Bonding Temperature ( $^{\circ}\text{C}$ )							
Retention Time (s)							
Applied Pressure (MPa)							
Bonding Atmosphere							
Heating Method for the Junction			High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)
Maximum Level Difference of the Junction (mm)							
Pipe Expansion Rate (%)							
Results of Junction Surface Penetrant Test			Cracks Present	No Cracks	Cracks Present	No Cracks	Cracks Present
Tensile Test Results	Tensile Strength (MPa)						
	Break Location		Bonding Boundary	Parent Material	Bonding Boundary	Parent Material	Bonding Boundary
Comprehensive Evaluation							

(0151)

In Comparative Example 6 in which the retention time at the bonding temperature was taken as 15 seconds, fissures were recognized in the junction in the penetrant test following pipe expansion. Moreover, the tensile strength was 563 MPa, and the specimen broke away from the bonding boundary. This is thought to have been because the diffusion of elements was not sufficiently performed because the retention time was short, and thus the deformability of the bonding boundary vicinity was diminished.

(0152)

Moreover, in Comparative Example 7 in which the applied pressure was taken as 1 MPa, although the retention time at the bonding temperature was taken as 300 seconds, fissures were recognized in the

junction in the penetrant test following pipe expansion. Also, the tensile strength was 628 MPa, and the specimen broke away from the bonding boundary. This is thought to have been because the bonding boundary did not sufficiently adhere and partially unbonded portions generated because the applied pressure was low, and therefore the deformability of the entire bonding boundary was diminished.

(0153)

Furthermore, in Comparative Example 8 in which the applied pressure was taken as 7 MPa, although the bonding temperature was reduced to 1250°C, excessive deformation occurred in the junction vicinity. Moreover, fissures were recognized in the junction in the penetrant test following pipe expansion. Furthermore, the tensile strength was 687 MPa, and the specimen broke away from the bonding boundary.

(0154)

In contrast to this, in Embodiment 10 in which the applied pressure was set to 5 MPa and the retention time was set to 30 seconds, and in Embodiment 11 in which the applied pressure was set to 1.5 MPa and the retention time was set to 300 seconds, no fissures were recognized on the bonding boundary in the penetrant test following pipe expansion for either of the embodiments. Moreover, the bonding strengths both exhibited strengths greater than 700 MPa, which is equivalent to that of the parent material, and the specimens broke away from the parent material side.

(0155)

Also, all of the end diameter expansion rates of the metal pipes were taken to be 15% in Embodiments 10 - 11 and Comparative Examples 6 - 8, so all of the maximum level differences were 0.5 mm.

(0156)

From the above results, it became clear that if the applied pressure is set greater than 1.5 MPa and less than 5 MPa in the case in which metal pipes are liquid phase diffusion bonded, then fissures will not generate on the junction following pipe expansion and metal pipe joints with high bond strength can be obtained.

(0157)

(Embodiment 12)

Pipe expansion was performed on a metal pipe joint using method A. A steel pipe was used with an external diameter of 10.75 inches (269 mm) and wall thickness 0.5 inches (13 mm) made from American Petroleum Institute Grade LC52-1200 (called "LC52-1200" hereafter), which is a type of martensitic stainless steel, and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 15%.

(0158)

Next, the end face of the expanded steel pipe was finished such that the surface roughness  $R_{max}$  is less than 50  $\mu\text{m}$ , a Ni-family alloy foil with melting point of 1140°C and thickness of 40  $\mu\text{m}$  that has a composition equivalent to JIS BNi-5 was placed on the bonding boundary of the metal pipe, and liquid phase diffusion bonding was performed. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 25%.

(0159)

Also, a high frequency induction heating method that uses a high frequency current with a frequency of 3 kHz was used as the heating method for the junction. Moreover, the bonding conditions were such that the bonding temperature was 1300°C, the retention time was 120 seconds, and the applied pressure was 4 MPa, and bonding was performed in an Ar atmosphere.

(0160)

(Embodiment 13)

Apart from setting the bonding temperature to 1350°C, the retention time to 210 seconds, the applied pressure to 3.5 MPa, and the frequency of the high frequency current that flows through the induction coil to 100 kHz, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 12.

(0161)

(Embodiment 14)

Apart from setting the bonding temperature to 1350°C, the retention time to 210 seconds, the applied pressure to 3.5 MPa, and performing bonding with a high frequency direct conduction heating method that uses a high frequency current with frequency of 25 kHz, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 12.

(0162)

(Comparative Example 9)

Apart from setting the surface roughness  $R_{max}$  of the bonding surface to 100  $\mu\text{m}$ , the bonding temperature to 1400°C, and the retention time to 300 seconds, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 12.

(0163)

(Comparative Example 10)

Apart from setting the retention time at the bonding temperature to 300 seconds, the applied pressure to 5 MPa, and the frequency of the high frequency current that flows through the induction coil to 400 kHz, the

manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 12.

(0164)

With respect to the metal pipe joints that were obtained in Embodiments 12 - 14 and Comparative Examples 9 - 10, maximum level difference tests, penetrant tests, and tensile tests were conducted in accordance with the same procedures as with Embodiment 1. The results are shown in Table 5.

(0165)

(Table 5)

[see source for numbers and English]

Test Number			Comparative Example 9	Embodiment 12	Comparative Example 10	Embodiment 13	Embodiment 14
Steel Pipe	Material						
	Dimensions	External Diameter (Inches)					
		Wall Thickness (Inches)					
End Diameter Expansion Rate (%)							
Bonding Surface Roughness (Rmax: $\mu\text{m}$ )							
Insert Material	Material						
	Melting Point ( $^{\circ}\text{C}$ )						
	Thickness ( $\mu\text{m}$ )						
	Form		Foil	Foil	Foil	Foil	Foil
Bonding Temperature ( $^{\circ}\text{C}$ )							
Retention Time (s)							
Applied Pressure (MPa)							
Bonding Atmosphere							
Heating Method for the Junction			High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (3 kHz)	High Frequency Induction Heating Method (400 kHz)	High Frequency Induction Heating Method (100 kHz)	High Frequency Induction Heating Method (25 kHz)
Maximum Level Difference of the Junction (mm)							
Pipe Expansion Rate (%)							
Results of Junction Surface Penetrant Test			Cracks Present	No Cracks	Cracks Present	No Cracks	No Cracks
Tensile Test Results	Tensile Strength (MPa)						
	Break Location		Bonding Boundary	Parent Material	Bonding Boundary	Parent Material	Parent Material
Comprehensive Evaluation							

(0166)

In Comparative Example 9 in which the surface roughness Rmax of the bonding boundary was set to 100  $\mu\text{m}$ , although diffusion bonding was performed under conditions of relatively high temperature, high pressure, and long time, fissures were recognized in the junction in the penetrant test following pipe expansion. Moreover, the tensile strength was 477 MPa, and the specimen broke away from the bonding boundary. This is thought to have been because it was not possible to fill with melted Ni alloy the irregularities that were present on the bonding boundary because the surface texture was rough, and therefore the deformability of the entire bonding boundary was diminished.

(0167)

Likewise, in Comparative Example 10 in which induction heating was performed using a high frequency current with a frequency of 400 MPa [sic], although diffusion bonding was performed under conditions of relatively high temperature, high pressure, and long time, fissures were recognized in the junction in the penetrant test following pipe expansion. Moreover, the tensile strength was 431 MPa, and the specimen broke away from the bonding boundary. This is thought to have been because the entire bonding boundary did not heat uniformly and unbonded portions generated on the inner periphery side of the metal pipe because the frequency was high, and therefore the deformability of the entire bonding boundary was diminished.

(0168)

In contrast to this, in Embodiments 12 - 14 in which the surface roughness  $R_{max}$  of the bonding boundary was set to 50  $\mu\text{m}$  and a high frequency current with a frequency less than 100 kHz was used, no fissures were recognized on the bonding boundary in the penetrant test following pipe expansion for any of the embodiments. Moreover, the bonding strengths all exhibited strengths greater than 700 MPa, which is equivalent to that of the parent material, and the specimens broke away from the parent material side.

(0169)

Also, all of the end diameter expansion rates of the metal pipes were taken to be 15% in Embodiments 12 - 14 and Comparative Examples 9 - 10, so all of the maximum level differences were 0.5 mm.

(0170)

From the above results, it became clear that if the surface roughness  $R_{max}$  of the bonding boundary is set to 50  $\mu\text{m}$  in the case in which metal pipes are liquid phase diffusion bonded, then fissures will not generate on the junction following pipe expansion and metal pipe joints with high bond strength can be obtained. Moreover, it became clear that if the frequency of the high frequency current is set below 100 kHz in the case in which the bonding boundary is heated through high frequency induction heating or high frequency direct conduction heating, it is possible to restrain the reduction of deformability that originates from the generation of unbonded portions.

(0171)

(Embodiment 15)

Pipe expansion was performed on a metal pipe joint using method B. A carbon steel pipe made from API 40H with an external diameter of 7 inches (178 mm) and wall thickness 0.231 inches (6 mm) was used for the metal pipe, and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 10%.

(0172)

Next, external thread was established on the end faces of the expanded metal pipes, and like metal pipes were fastened to one another with a coupling that has internal thread that can screw into this external thread. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 10%.

(0173)

(Embodiment 16)

Apart from setting the end diameter expansion rate of the metal pipe to 25% and expanding the metal pipe joint with a 25% pipe expansion rate, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 15.

(0174)

(Embodiment 16 [sic])

Apart from using as the metal pipe a steel pipe made from LC52-1200 with an external diameter of 10.75 inches (273 mm) and wall thickness 0.5 inches (127 mm), setting the end diameter expansion rate to 25%, and expanding the metal pipe joint with a 25% pipe expansion rate, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 15.

(0175)

(Comparative Example 11)

Apart from setting the end diameter expansion rate of the metal pipe to 0%, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 15.

(0176)

(Comparative Example 12)

Apart from using as the metal pipe a steel pipe made from LC52-1200 with an external diameter of 10.75 inches (273 mm) and wall thickness 0.5 inches (127 mm), setting the end diameter expansion rate to 15%, and expanding the metal pipe joint with a 25% pipe expansion rate, the manufacturing and expansion of the metal pipe joint were performed in accordance with the same procedures as with Embodiment 15.

(0177)

Hydraulic pressure tests were conducted with respect to each of the metal pipe joints that were obtained in Embodiments 15 - 17 and Comparative Examples 11 - 12. The results are shown in Table 6.

(0178)

(Table 6)

[see source for numbers and English]

Test Number			Comparative Example 11	Embodiment 15	Embodiment 16	Embodiment 17	Comparative Example 12
Steel Pipe	Material						
	Dimensions	External Diameter (Inches)					
		Wall Thickness (Inches)					
End Diameter Expansion Rate (%)							
Pipe Expansion Rate (%)							
Hydraulic Pressure Test Pressure (psi)							
Hydraulic Pressure Test Results			Leak Generation	Satisfactory	Satisfactory	Satisfactory	Leak Generation
Comprehensive Evaluation							

(0179)

With respect to Comparative Example 11 in which the end diameter expansion rate was set to 0% and the metal pipe joint was expanded with a 10% pipe expansion rate, water leaks generated from the junction after having performed a hydraulic pressure test with 2100 psi pressure.

(0180)

In contrast to this, in Embodiment 15 in which both the end diameter expansion rate and the pipe expansion rate were set to 10%, and in Embodiment 16 in which both the end diameter expansion rate and the pipe expansion rate were set to 25%, water leaks did not generate from either of the junctions even when hydraulic pressure tests were performed with 2100 psi pressure.

(0181)

Moreover, with respect to Comparative Example 12 in which the end diameter expansion rate was set to 15% and the metal pipe joint was expanded with a 20% pipe expansion rate, water leaks generated from the junction after having performed a hydraulic pressure test with 3000 psi pressure.

(0182)

In contrast to this, in Embodiment 17 in which both the end diameter expansion rate and the pipe expansion rate were set to 25%, water leaks did not generate from the junction even when a hydraulic pressure test was performed with 3000 psi pressure, and a satisfactory metal pipe joint was obtained.

(0183)

From the above results, it became clear that, in the case in which a metal pipe joint that was bonded with a threaded connection method is expanded, if pipe expansion is performed with a pipe expansion rate that is less than the end diameter expansion rate, a metal pipe joint that is superior with respect to airtightness can be obtained.

(0184)

(Embodiment 18)

Pipe expansion was performed on a metal pipe joint using method C. A steel pipe made from STKM12B (JIS G3445) with an external diameter of 140 mm and wall thickness of 7 mm was used for the metal pipe. The end face of this steel pipe was finished such that the surface roughness  $R_{max}$  is less than 30  $\mu\text{m}$ , a Ni-family alloy foil with a melting point of 1050°C and thickness of 50  $\mu\text{m}$  that has a composition equivalent to JIS BNi-3 was placed on the bonding boundary, and diffusion bonding was performed. Furthermore, the

obtained metal pipe joint was expanded with a mandrel such that the pipe expansion rate was between 5 - 25%.

(0185)

Also, a high frequency induction heating method that used a high frequency current with a frequency of 3 kHz was used as the heating method for the junction, and two types of coils were used for the heating coils – a coil in which the heating width is 20 mm, and a coil in which the heating width is 40 mm.

Moreover, as for the bonding conditions, the bonding temperature was set between 1250 - 1350°C, the retention time was set between 60 - 300 seconds, the applied pressure was set between 1 - 4 MPa, and bonding was performed within an Ar atmosphere. Furthermore, the lateral expansion rate was adjusted by modifying the bonding conditions.

(9810)

The lateral expansion rates and expansion lengths of the obtained metal pipe joints and the presence of cracks and tensile strengths following pipe expansion are shown in Table 7. Also, the tensile strengths (notated as “parent material” in Table 7) of the non-conjugative regions of the metal pipes that were expanded with prescribed pipe expansion rates are also included in Table 7.

(0187)

(Table 7)

[see source for numbers and English]

Test Number	Bonding Conditions			Lateral Expansion Rate (%)	Heating Width (mm)	Expansion Length (mm)	Tensile Strength Before Pipe Expansion (MPa)	Junction Expansion Test Results											
	Bonding Temperature (°C)	Retention Time (s)	Applied Pressure (MPa)					Pipe Expansion Rate 5%		Pipe Expansion Rate 10%		Pipe Expansion Rate 15%		Pipe Expansion Rate 20%		Pipe Expansion Rate 25%			
								Crack Presence	Tensile Strength (MPa)	Crack Presence	Tensile Strength (MPa)	Crack Presence	Tensile Strength (MPa)	Crack Presence	Tensile Strength (MPa)	Crack Presence	Tensile Strength (MPa)		
								None		Present							Present		
								None		Present							Present		
								None		None							Present		
								None		None							Present		
								None		None							None		
								None		None							None		
								None		None							None		
								None		None							None		
								None		None							None		
								None		None							None		
								None		None							None		
Parent Material								None		None							None		

(0188)

It can be seen from Table 7 that the expansion length becomes longer as a heating coil with a long heating width is used. In other words, it can be seen that the expansion length becomes 40 - 50 mm if the heating width is set to 20 mm, and the expansion length becomes 80 - 90 mm if the heating width is set to 40 mm.

(0189)

Moreover, it can be seen from Table 7 that, in the case in which the expansion length is set between 40 - 50 mm, a metal pipe joint is obtained in which pipe expansion can be performed with a larger pipe expansion rate as the lateral expansion rate becomes larger.

(0190)

Stated simply, in the case in which the lateral expansion rate is 1.00, cracks already generated on the bonding boundary when the pipe expansion rate was 10%, and a sound metal pipe joint was not obtained (Test Number 1). When the lateral expansion rate was set to 1.02, a sound metal pipe joint was obtained in the case in which the pipe expansion rate was less than 15%, but fissures generated in the junction when the pipe expansion rate was greater than 20% (Test Number 3).

(0191)

In contrast to this, when the lateral expansion rate was set greater than 1.04 (Test Numbers 5, 7, 9, and 11), no fissures generated in the junctions even when the pipe expansion rate was set to 20%, and sound metal pipe joints that have strengths equivalent to the parent material were obtained.

(0192)

The case in which the expansion length was set between 80 - 90 mm was the same, and it can be seen that a metal pipe joint is obtained in which pipe expansion can be performed with a larger pipe expansion rate as the lateral expansion rate becomes larger (Test Numbers 2, 4, 6, 8, 10).

(0193)

Furthermore, it can be seen from Table 7 that, in the case in which the lateral expansion rate is made to be uniform, there is a tendency for metal pipe joints to be obtained that can withstand pipe expansion with a larger pipe expansion rate as the expansion length becomes longer. In other words, in the case in which the lateral expansion rate was 1.02 and the expansion length was 40 mm, fissures generated in the junction when pipe expansion was performed with a pipe expansion rate of 20% (Test Number 3). On the other hand, in the case in which the expansion length was set to 80 mm, no fissures generated in the joint even when pipe expansion was performed with a pipe expansion rate of 20%, and a sound joint that has strength equivalent to the parent material was obtained (Test Number 4).

(0194)

Likewise, in the case in which the lateral expansion rate was 1.04 and the expansion length was 45 mm, fissures generated in the junction when pipe expansion was performed with a pipe expansion rate of 25% (Test Number 5). On the other hand, in the case in which the expansion length was set to 90 mm, no fissures generated in the junction even when pipe expansion was performed with a pipe expansion rate of 25%, and a sound joint that has the strength equivalent to the parent material was obtained (Test Number 6).

(0195)

From the above results, it became clear that if metal pipes whose ends have not been expanded are butted and the bonding boundary vicinity is deformed into a barrel shape with a prescribed lateral expansion rate at the time of diffusion bonding, then fissures will not generate in the junction even in the case in which pipe expansion is performed with a high pipe expansion rate, and a sound metal pipe joint with high bonding strength can be obtained.

(0196)

(Embodiment 19)

Pipe expansion was performed on a metal pipe joint using method A'. A carbon steel pipe made from API H40 with an external diameter of 7 inches (178 mm) and wall thickness 0.231 inches (6 mm) was used for the metal pipe, and the end internal diameter of this steel pipe was expanded such that the end diameter expansion rate was 5%.

(0197)

Next, grooves were formed on the end faces of the expanded metal pipes, and the metal pipes were welded with a gas shield arc welding method. Furthermore, the obtained metal pipe joint was expanded using a mandrel such that the pipe expansion rate was 25%.

(0198)

Also, welding was performed using JIS YGW21 (Ø1.2 mm) as the welding wire and a mixed gas of Ar + 20%CO<sub>2</sub> as the shield gas, with a 280A welding current.

(0199)

(Embodiments 20 - 21, Comparative Examples 13 - 14)

Apart from respectively setting the end diameter expansion rates of metal pipes 30 to 0% (Comparative Example 13), 3% (Comparative Example 14), 10% (Embodiment 20), and 15% (Embodiment 21), the manufacturing and expansion of the metal pipe joints were performed in accordance with the same procedures as with Embodiment 19.

(0200)

With respect to the metal pipe joints that were obtained in Embodiments 19 - 21 and Comparative Examples 13 - 14, penetrant tests and tensile tests were performed in accordance with the same procedures as with Embodiment 1. The results are shown in Table 8.

(0201)

(Table 8)

[see source for numbers and English]

Test Number			Comparative Example 13	Comparative Example 14	Embodiment 19	Embodiment 20	Embodiment 21
Steel Pipe	Material						
	Dimensions	External Diameter (Inches)					
		Wall Thickness (Inches)					
End Diameter Expansion Rate (%)							
Welding Method			Gas Shield Arc Welding Method Welding Wire: JIS YGW21 (Ø1.2 mm) Shield Gas: Ar + 20%CO2 Welding Current: 280A				
Pipe Expansion Rate (%)							
Results of Junction Surface Penetrant Test			Cracks Present	Cracks Present	No Cracks	No Cracks	No Cracks

Tensile Test Results	Tensile Strength (MPa)					
	Break Location	Welded Section	Welded Section	Parent Material	Parent Material	Parent Material
Comprehensive Evaluation						

(0202)

In Comparative Example 13 in which the end diameter expansion rate was set to 0%, multiple fissures were recognized in the junction in the penetrant test following pipe expansion. Furthermore, the tensile strength exhibited low strength of 317 MPa, and the specimen broke away from the welded section.

(0203)

Likewise, in Comparative Example 14 in which the end diameter expansion rate was set to 3%, significant fissures were recognized in the junction in the penetrant test following pipe expansion, but the number of fissures was less than in Comparative Example 13. Accordingly, the tensile strength improved to 495 MPa, but the specimen broke away from the welded section.

(0204)

In contrast to this, in Embodiments 19, 20, and 21 in which the end diameter expansion rates were respectively set to 5%, 10%, and 15%, no fissures were recognized on the bonding boundary in the penetrant tests following pipe expansion in any of the embodiments. Furthermore, the bonding strengths all exhibited strengths greater than 700 MPa, which is equivalent to that of the parent material, and the specimens broke away from the parent material side.

(0205)

From the above results, it became clear that if the end internal diameter of the metal pipe is expanded before the metal pipes are welded such that a value greater than the prescribed end diameter expansion rate is achieved, it becomes more difficult for fissures to generate on the junction at the time of pipe expansion as the end diameter expansion rate becomes larger, and a metal pipe joint with higher bonding strength can be obtained.

(0206)

The embodiments of the present invention were described in detail above, but the present invention is in no way limited to the embodiments described above, and various alterations are possible within a scope that does not deviate from the purport of the present invention.

(0207)

For example, there are no particular restrictions regarding the shape of the mandrel that is used for pipe expansion, and it would be acceptable to use a tapered mandrel or a mandrel that has a roller on the tapered surface.

(0208)

Moreover, there are also no particular restrictions regarding the drive means for the mandrel. For example, it would be acceptable to affix a shaft to the base surface of the mandrel, and then drive the mandrel into the metal pipe joint using that shaft.

Alternatively, it would also be acceptable to apply hydraulic pressure to the base surface of the mandrel, and then move it through the metal pipe joint from one end to the other with hydraulic pressure.

(0209)

Moreover, in the embodiments described above, a diffusion bonding method, a threaded connection method, or a welding method was used to bond metal pipe joints in which the internal diameter of the junction has become larger than the internal diameter of the non-conjugative regions, but the bonding method of the metal pipes joints is not limited to these methods. For example, it would also be acceptable to form a metal pipe joint by bonding metal pipes with a friction pressure welding method.

(0210)

Furthermore, the metal pipe joint for pipe expansion and its manufacturing method of the present invention are particularly suited for oil well pipes for casing that is buried beneath the earth and the manufacturing method thereof, but the applications of the present invention are not limited to oil well pipes, and it is possible to use them as casing that is used in natural gas wells, geothermal wells, hot spring wells, and water wells, or as line pipe that is laid on the ground surface or as plumbing for plants and the manufacturing methods thereof. By doing so, it is possible to obtain effects equivalent to those of the embodiments above.

(0211)

(Effects of the Invention)

The metal pipe joint for pipe expansion and its manufacturing method of the present invention uses an industrial tool such as a mandrel to expand a metal pipe joint in which the internal diameter of the junction has become larger than the internal diameter of the non-conjugative regions, so the deformation resistance when expanding the metal pipe joint becomes small. Therefore, it is possible to perform the pipe expansion operation smoothly, and there is the effect that motive energy of the pipe expansion operation is also conserved.

(0212)

Moreover, if the diameter of the end of the metal pipe is expanded in advance with a prescribed end diameter expansion rate and such metal pipes are butted and diffusion bonded or welded, then it is possible to easily obtain a metal pipe joint in which the internal diameter of the junction has become larger than the internal diameter of the non-conjugative regions.

(0213)

Furthermore, in the case in which such a metal pipe joint is expanded, it is possible to make the plastic stress of the junction small in comparison to the plastic stress of the non-conjugative regions. Therefore, even in the case in which heat-affected regions generate at the time of diffusion bonding or welding and the deformability of the junction vicinity is diminished, there is the effect that it becomes difficult for fissures to generate on the junction, and a metal pipe joint that is superior with respect to strength and airtightness can be obtained.

(0214)

Moreover, if metal pipes whose end internal diameters have been expanded with a prescribed end diameter expansion rate are bonded with a threaded connection method to form a metal pipe joint, there is the effect that the thread portions do not plastic-deform, so there is no decrease in airtightness that originates from loose thread.

(0215)

Moreover, even in the case in which like metal pipes whose ends have not been expanded are butted and the junction is deformed into a barrel shape with a prescribed lateral expansion rate at the same time that the metal pipes are diffuse bonded, it is possible to easily obtain a metal pipe joint in which the internal diameter of the junction has become larger than the internal diameter of the non-conjugative regions.

Therefore, if such a metal pipe joint is expanded with a prescribed pipe expansion rate, there is the effect that a metal pipe joint that is superior with respect to strength and airtightness can be obtained.

(0216)

Furthermore, in the case in which the ends of metal pipes are expanded in advance with a prescribed end diameter expansion rate and such metal pipes are butted and diffusion bonded, it is possible to reduce the level differences that generate on the inner periphery side of the junction, even if there is variation in the dimensions of each metal pipe. Therefore, even if pipe expansion is performed, there is no danger of the generation of fissures that originate from stress concentration, so there is the effect that a metal pipe joint that is superior with respect to strength, fatigue characteristics, and corrosion resistance can be obtained.

(0217)

As described above, through the metal pipe joint for pipe expansion and its manufacturing method, it is possible to easily obtain a metal pipe joint in which the energy expenditure required for pipe expansion is small, airtightness and strength are superior, and the level differences that generate in the junction are small. Therefore, if this is applied to an oil well pipe or line pipe, for example, it will contribute to significant cost reduction and reliability improvement in the oil drilling operation or pipe laying operation, and the present invention is an invention in which these effects are extremely large industrially.

#### (Brief Description of the Drawings)

(Figure 1)

A flow chart that shows the metal pipe joint for pipe expansion and its manufacturing method of the first embodiment of the present invention.

(Figure 2)

A flow chart that shows the pipe expansion method of the metal pipe joint for pipe expansion shown in Figure 1 (d).

(Figure 3)

A flow chart that shows the metal pipe joint for pipe expansion and its manufacturing method of the second embodiment of the present invention.

(Figure 4)

A flow chart that shows the pipe expansion method of the metal pipe joint for pipe expansion shown in Figure 2 (d).

(Figure 5)

Figure 5 (a) - (c) is a flow chart that shows metal pipe joint for pipe expansion and its manufacturing method of the third embodiment of the present invention, and Figure 5 (d) is a figure that shows the expansion method of the metal pipe for pipe expansion shown in Figure 5 (c).

(Figure 6)

A cross sectional diagram that shows the typical structure of an oil well.

(Figure 7)

A cross sectional diagram that shows the threaded connection method (mechanical coupling method).

#### (Explanation of Symbols)

30, 40, 50	Metal Pipes
32, 42, 52	Metal Pipe Joints
34	Mandrel

[see source for drawings]

(Figure 1)

(c)

Machine work

Machine work

(Figure 3)

(Figure 2)

Applied pressure

(Figure 6)

(Figure 4)  
Applied pressure

(Figure 7)

(Figure 5)

(b)  
Applied pressure          Applied pressure

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(72) Inventor: Shigeyuki Inagaki  
Aichi-ken, Nagoya-shi, Minami-ku, Tenpaku-cho, 3-9-111  
Daido Steel Tenpaku Manor 205

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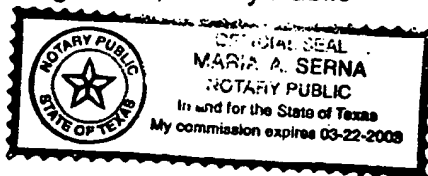
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Kim Stewart  
TransPerfect Translations, Inc.  
3600 One Houston Center  
1221 McKinney  
Houston, TX 77010

ATLANTA  
BOSTON  
BRUSSELS  
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Stamp, Notary Public

Harris County

Houston, TX

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(71) 出願人 000003713

大同特殊鋼株式会社

愛知県名古屋市中区錦一丁目11番18号

(72) 発明者 山田 龍三

愛知県知多市大草四方田48番地の1

(72) 発明者 堀尾 浩次

愛知県東海市加木屋町南産持18

(72) 発明者 冷水 孝夫

愛知県名古屋市中区表山2丁目311番地

八事サンハイツ501

(74) 代理人 100095669

弁理士 上野 登 (外1名)

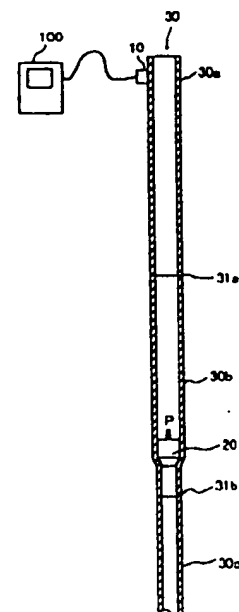
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(54) 【発明の名称】 拡張時の品質監視方法

(57) 【要約】

【課題】 鋼管の拡張時に発生した品質異常の発生或いはその品質異常の程度を判定し、リモートで監視することができる拡張時の品質監視方法を提供することにある。

【解決手段】 拡張マンドレル20が鋼管30の内部を移動しながら拡張する際に、鋼管の振動を検出するAEセンサ10を鋼管に当接させて設け、AEセンサ信号の振幅が増大したこと、AEセンサ信号の振幅の増大した回数若しくはAEセンサ信号の振幅の増大した時間を検出し、その検知信号に基づいて、前記鋼管30の品質異常の発生若しくはその品質異常の程度を判定するようにした。



**【特許請求の範囲】**

【請求項1】 鋼管の拡張時に該鋼管の振動を検出するA Eセンサを鋼管に当接させて設け、拡張マンドレルが鋼管の内部を移動しながら拡張する際に、A Eセンサ信号の振幅が増大したこと、A Eセンサ信号の振幅の増大した回数若しくはA Eセンサ信号の振幅の増大した時間を検知し、その検知信号に基づいて前記鋼管の品質異常の発生を判定するようにしたことを特徴とする拡張時の品質監視方法。

【請求項2】 前記品質異常を判定した際に検知されるA Eセンサ信号の振幅の大きさ、A Eセンサ信号の振幅が増大した回数若しくはA Eセンサ信号の振幅の増大した時間に基づいて前記鋼管の品質異常の程度を判定するようにしたことを特徴とする請求項1に記載の拡張時の品質監視方法。

【請求項3】 拡張マンドレルが鋼管の内部を移動しながら拡張する際に検出されるA Eセンサの信号を増幅すると共に、A Eセンサ信号の振幅の連続的な減少に応じて前記増幅の度合を高め、A Eセンサの振幅の連続的な増加に応じて前記増幅の度合を低下させるようにしたことを特徴とする請求項1又は2に記載される拡張時の品質監視方法。

**【発明の詳細な説明】****【0001】**

【発明の属する技術分野】 本発明は、拡張時の品質監視方法に関し、特に長尺の鋼管等を拡張するときに鋼管の継目等に発生するクラックやピンホール等の品質異常を監視するのに好適な拡張時の品質監視方法である。

**【0002】**

【従来の技術】 従来、鋼材による長尺管を拡張するに際しては、拡張マンドレルを使用して拡張することが行なわれている。これは、図1に示したように、長尺管30の一方の開口端より拡張マンドレル20を挿通し、所定の荷重Pを印加してこの拡張マンドレル20を長尺管30に押し込むことにより、長尺管30の内壁面を外方へ押し出し、拡張していくものである。

【0003】ところで、この拡張加工によって鋼管に例えばひび割れのような品質異常が発生する場合がある。特に、例えばメカジョイント、溶接又は拡散接合等による接合部分を有する鋼管の拡張においては、その接合部分に品質異常が発生しやすい。このような品質異常を検出するために、従来、例えば、超音波を被検査体に放射し欠陥面と端面との反射波の違いにより、内部欠陥を発見する超音波探傷法や、被検査体にX線を当てて、その透過放射線をフィルム感光させて、その感光像から欠陥を検出するX線探傷法といった非破壊検査が行なわれている。

【0004】しかし、これらの検査方法を行なうには検査装置の少なくとも一部分を検査したい部位に設置させなければならないという問題があり、これは、鋼管が長

くなるほど大きな問題となる。また、これらの検査方法では、拡張作業中の部位では行うことができず、少なくとも検査部位の拡張が終了した後に行なわなければならないという問題もあった。即ち、従来の検査方法では、拡張をした後に、検査する部位に検査装置の少なくとも一部を設置して検査を行なう必要があった。

【0005】一方、従来、地下の石油等を吸い上げるための油井用パイプを設置するにあたり、その埋設コストを下げるため、径の比較的小さい鋼管を地中に挿入した後、拡張マンドレル等を高圧で後方からの押圧により挿通させて拡張する技術が知られている。このように拡張された鋼管を従来の方法で検査するためには、該鋼管は地中に埋設されているため、鋼管の外壁面に検査装置等を設置することが困難であり、検査装置を鋼管の外壁に沿って長さ方向に移動させることは更に困難であったため、鋼管の内部を検査装置を移動させて検査する必要があるが、拡張後であってもその管径は小さく、またその全管長は数キロメートルに及ぶこともあるため、鋼管全体について従来の方法で品質異常の検査をすることは非常に困難であるという問題があった。

**【0006】**

【発明が解決しようとする課題】 本発明の解決しようとする課題は、鋼管の拡張作業中に監視装置が静止した状態で鋼管の品質異常を判定することができ、品質監視装置から離れた部位の品質異常の発生又は程度を判定することができ、かつ、該鋼管の品質異常発生とほぼ同時にその発生を検出することができる拡張時の品質監視方法を提供することにある。

**【0007】**

【課題を解決するための手段】 この課題を解決するために本発明に係る拡張時の品質監視方法は、鋼管の拡張時に該鋼管の振動を検出するA Eセンサを鋼管に当接させて設け、拡張マンドレルが鋼管の内部を移動しながら拡張する際に、A Eセンサ信号の振幅が増大したこと、A Eセンサ信号の振幅の増大した回数若しくはA Eセンサ信号の振幅の増大した時間を検知し、その検知信号に基づいて前記鋼管の品質異常の発生を判定するようにしたことを要旨とするものである。

【0008】このように行なう本発明の拡張時の品質監視方法によれば、拡張マンドレルが鋼管の内部を移動しながら拡張する際の鋼管面及び鋼管内部に発生する振動を、鋼管に設置されたA Eセンサによって検出し、前記A Eセンサ信号の振幅が増大したことを検知した場合に品質異常が発生したと判定し、前記A Eセンサの信号の振幅が増大した回数が予め設定した回数に達したことを検知したときに品質異常が発生したと判定し、若しくは、前記A Eセンサの信号の振幅が増大した時間が予め設定した時間に以上になったことを検知した場合に品質異常が発生したと判定するものである。

【0009】また、請求項2に記載の発明のように、前

記品質異常を判定した際に検知されるAEセンサ信号の振幅の大きさ、AEセンサ信号の振幅が増大した回数若しくはAEセンサ信号の振幅の増大した時間に基づいて前記鋼管の品質異常の程度を判定するようにすれば、前記AEセンサ信号の振幅の大きさに基づいて前記鋼管の品質異常の程度を判定でき、前記AEセンサ信号の振幅が増大した回数に基づいて前記鋼管の品質異常の程度を判定することができ、若しくは、AEセンサ信号の振幅の増大した時間に基づいて鋼管の品質異常の程度を判定することができる。

【0010】更に、請求項3に記載の発明のように、拡張マンドレルが鋼管の内部を移動しながら拡張する際に検出されるAEセンサの信号を増幅すると共に、AEセンサ信号の振幅の連続的な減少に応じて前記増幅の度合を高め、AEセンサの振幅の連続的な増加に応じて前記増幅の度合を低下させるようにすると良い。

【0011】このように行なう本発明の請求項3に記載の拡張時の品質監視方法によれば、拡張マンドレルが鋼管の内部を移動しながら拡張する際に検出されるAEセンサの信号を増幅すると共に、拡張により発生する振動がAEセンサまで伝搬することによって生じる減衰が大きくなると前記増幅の度合を増加させ、前記減衰が低下すると前記増幅の度合を減少させるように調整するので、拡張により発生する振動がAEセンサまで伝搬することによって生じる減衰が補正され、該補正されたAEセンサ信号に基づいて品質監視が行なわれる。

【0012】ここで、増幅の度合の変化をAEセンサ出力振幅の連続的な減少又は連続的な増加に応じて行なうこととしているのは、拡張により発生する振動の大きさが比較的安定しておりAEセンサの出力振幅が連続的に変化する部位の拡張振動を基準とすることを意味し、例えば、異常発生時のAEセンサ信号振幅の変化のように非連続的な振幅変化については前記増幅度を追従させないことを意味する。このように非連続変化部分を除いたAEセンサ信号振幅の変化に基づいて補正をすることにより、品質異常等が発生して監視時刻のAE信号振幅が一時的に増大又は減少しても誤った補正をすることなく、減衰を適確に補正する。

【0013】

【発明の実施の形態】以下に本発明の好適な実施の形態を図面を参照して詳細に説明する。図1は、本発明に係る鋼管の拡張時の品質監視方法の概念を説明するために示した概略構成図である。長尺管30については、断面を示している。該長尺管30は、比較的短い鋼管30a、30b、30c・・・が接合部31a、31b・・・において接合されたものである。図においては、鋼管の3本分しか示されていないが、更に下方に続いている。

【0014】拡張マンドレル20は図示のようにテーパー部分と円柱部分とを有し、後方（図面においては上方）

から荷重Pを負荷され、前方（図面においては下方）に進行しながら前記テーパー部分により長尺管の内壁面を半径方向外方に押し広げて、前記長尺管30を拡張するものである。AEセンサ10は長尺管の外側面に接触する状態で設置され、前記拡張が行われているときの該外側面の振動を信号に変換するものであり、監視装置本体100に接続されて該信号を出力する。

【0015】図2は、本発明に適用される品質監視装置の信号処理構成例を示す制御ブロック図である。（a）に示す品質監視装置本体100においては、AEセンサ10は絶対値処理部101に接続され、絶対値処理部101は比較処理部103に接続され、異常判定基準値設定部102も比較処理部103に接続され、比較処理部103は告知手段110に接続される。

【0016】前記絶対値処理部101はAEセンサ10の出力信号の直流分を取り除き絶対値化した信号を出力する。前記異常判定基準値設定部102はAEセンサ10の信号振幅の大きさを判断するための閾値である異常判定基準値 $Th1$ を設定する部分であり、異常判定基準値 $Th1$ は、異常なく拡張が行なわれている時のAEセンサ信号振幅と品質異常が発生したときAEセンサ信号振幅との間の値になるように設定されればよい。

【0017】例えば、基準値設定つまみを設けて拡張対象の鋼管の種類に応じて予め実験的に得られた異常判定基準値を操作者が設定するようにしても良いが、ここでは、該長尺管30の拡張加工を始めた初期段階の時刻 $t_s$ のAEセンサ信号振幅 $A_s$ に予め設定した係数 $k1$ （但し、 $k1 > 1$ ）を乗じた値を自動的に設定する様にする。

【0018】前記比較処理部103は、絶対値処理部101から入力される信号を前記異常判定基準値 $Th1$ と比較して、絶対値処理部101の信号が異常判定基準値 $Th1$ を超えた場合に高値発生信号を出力する。告知手段110は、前記高値発生信号が入力されたときに、品質異常が発生したものと判定し、その旨を音声或いは表示によって操作者に通知する。

【0019】このようにして、（a）に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号は直流分を除去され整流され振幅を取得されて、AEセンサ10の信号振幅が異常判定基準値を超えた場合に異常発生が告知される。

【0020】（b）に示す品質監視装置本体100は、図からもわかるように、前記（a）に示す品質監視装置の構成の比較処理部103と告知手段110との間にパルス計数部104が介設されたものである。パルス計数部104は、比較処理部103及び告知手段110と接続される。そして、比較処理部103から受けた前記高値発生信号の回数を計数し、その回数が予め設定した回数以上になった場合に、品質異常発生信号を出力する。ここでは、高値発生信号の発生回数が2回以上になった

ときに、品質異常発生信号を出力することにする。

【0021】従って、(b)に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号は直流分を除去され整流されてその振幅を取得されて、AEセンサ10の信号振幅が異常判定基準値を超えた回数が2回以上の場合に、品質異常発生旨が告知される。

【0022】更に、この場合に、パルス計数部104は、前記品質異常発生信号に加えて、高値発生信号の回数を告知手段110に伝送し、告知手段110は品質異常発生旨及び前記高値発生信号の回数に応じた品質異常の程度を告知するように構成しても良い。例えば、高値発生回数そのものを告知するようにしても良いが、ここでは、2回ないし3回の場合には異常の程度が「弱」である旨を、4回ないし5回の場合には異常の程度が「中」である旨を、6回以上場合には異常の程度が「強」である旨を告知するようにする。

【0023】(c)に示す品質監視装置本体100は、(a)に示す品質監視装置にピーク値検出部107を増設したものである。ピーク値検出部107には絶対値処理部101の出力及び比較処理部103の出力が入力されると共に、告知手段110に接続される。ピーク値検出部107は、前記比較処理部103から前記高値発生信号が出力された場合に、そのときの絶対値処理部101の出力のピーク値を保持し、前記告知手段110に出力する。

【0024】そして、告知手段110は、品質異常の発生旨及び前記ピーク値に基づいて品質異常の程度を告知する。例えば、ピーク値の大きさそのものを告知するようにしても良いが、ここでは、ピーク値の大きさにより異常の程度を「強」、「中」又は「弱」に判別し、その判別結果を告知するようにする。

【0025】(c)に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号は直流分を除去され整流されて振幅を取得されて、AEセンサ10の信号振幅が異常判定基準値 $T_{h1}$ を超えた場合には、異常発生旨と該品質異常が発生したときのAEセンサ信号振幅のピーク値に基づく品質異常の程度とが、音声又は表示によって通知される。

【0026】(d)に示す品質監視装置本体100は、(a)に示す品質監視装置の絶対値処理部101と比較処理部103との間に包絡線検波部106を増設し、比較処理部103と比較処理部103と告知手段110との間にパルス幅判定部108を増設したものである。前記包絡線検波部106は、絶対値処理部101の出力信号の各極大値を結ぶ包絡線信号を出力し、比較処理部103に伝送する。比較処理部103は、包絡線検波部106の出力が前記異常判定基準値 $T_{h1}$ よりも大きい時に高値発生信号を告知手段110に出力する。パルス幅判定部108は前記高値発生信号の時間が所定の時間よりも長いときには、

異常発生旨及び前記高値発生時間の長さを告知手段110に伝達する。

【0027】そして、告知手段110は、品質異常の発生旨及び前記高値発生信号時間の長さに基づいて品質異常の程度を告知する。例えば、前記高値発生信号時間の長さそのものを告知するようにしても良いが、ここでは、前記高値発生信号時間の長さにより異常の程度を「強」、「中」又は「弱」に判別し、その判別結果を告知するようにする。

【0028】(d)に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号から直流分を除去され整流された信号の包絡線強度が異常判定基準値を超えた時間を計測し、該時間が所定の時間よりも長い場合に、異常発生旨と包絡線強度が異常判定基準値 $T_{h1}$ を超えた時間に基づく品質異常の程度とが、音声又は表示によって通知される。

【0029】図3は、図2(a)、(b)及び(c)に共通する各処理部の信号波形を概念的に示した図である。図3は、具体的には、図1に示す品質監視構成において、拡張時に接続部31bで品質異常が発生した場合の品質監視装置本体100の各部で出力される波形を示したものであり、(a)はAEセンサ10の出力信号を示し、(b)は絶対値処理部101の出力信号を示し、(c)は比較処理部103の出力信号を示す。

【0030】(a)に示す波形を順に説明する。時刻 $t_0$ に拡張マンドレル20の進行によって拡張加工が開始すると、該進行時の拡張マンドレル10と長尺管30との摩擦による振動及び拡張による塑性変形等によって生じるいわゆるアコースティックエミッション(AE)による振動等(以下、これらをまとめて拡張振動という。)が発生する。この拡張振動は品質異常が発生していない場合には、比較的弱い弾性波である。従って、鋼管30aの拡張中である時刻 $t_0$ から $t_1$ までの時間には、AEセンサ10は比較的小さい振幅の信号波形を出力する。

【0031】次に、接合部31aの拡張をする時刻 $t_1$ から $t_2$ の時間は、該接合部31aは例えばメカジョイント、拡散接合、溶接等により接合されており、その硬度が鋼管30aよりも高いため拡張マンドレル20の進行が遅くなり、前記拡張振動は、更に弱い振幅の振動となるため、この時間はAEセンサ10は時刻 $t_0$ から $t_1$ よりも小さい振幅の信号波形を出力する。鋼管30bを拡張する時刻 $t_2$ から $t_3$ までの時間には、前記時刻 $t_0$ から $t_1$ までの時間と同様に、AEセンサ10は比較的弱い振幅の信号波形を出力する。

【0032】そして、次の接合部31bの拡張中にひび割れが発生すると、その破壊によりエネルギーが発散され比較的大きな振幅の弾性波が生じる。AEセンサ10は該弾性波を含む拡張振動を検出して、時刻 $t_3$ から $t_4$ の時間には、比較的大きな振幅の信号波形を出力す

る。以降、図からわかるようにAEセンサ10は、鋼管31cを拡張する時刻t4からt5の時間には比較的小振幅の信号波形を、図示しないその次の接合部を拡張する時刻t5からt6の時間は更に小さい振幅の信号波形を出力する。

【0033】一方、絶対値処理部101の出力波形は、(a)に示すAEセンサ出力の直流分を除去し絶対値化したものであり、(b)に示す如き波形となる。また、比較処理部103は、前記絶対値処理部101の出力信号を前記のように設定された異常判定基準値TH1と比較して、該基準値TH1よりも大きいときには「Hi」を出力し、該基準値よりも小さいときには「Lo」を出力する。

【0034】従って、比較処理部103は、(b)に示す絶対値処理部101の出力信号が入力されると、

(c)に示す波形を出力する。時刻t0からt3の時間は、絶対値処理部101からは前記異常判定基準値TH1よりも大きな入力がないので出力は「Lo」のままである。次に、前記のように時刻t3からt4の時間にひび割れが発生するので、(b)に示すように、前記異常判定基準値TH1よりも大きな振幅の信号が入力され、

(c)において時刻t3からt4の時間に、パルスP1からP3を出力する。続いて、時刻t4からt6の時間は、前記基準値TH1よりも大きな入力がないので、再び「Lo」のままである。

【0035】図2の(a)ないし(c)の構成を有する品質監視装置本体100の夫々は、これらの図3(a)ないし(c)に示す出力信号に基づいて、次のように処理をする。図2(a)に示す品質監視装置本体100は、比較処理部103から「Hi」のパルスが出力されたので、告知手段110へ異常発生信号を発し、告知手段110が異常の発生を告知する。

【0036】図2(b)に示す品質監視装置本体100は、比較処理部103から出力されるパルスの回数が3回であり、2回以上に該当するので品質異常発生を告知する。また、高値発生信号であるパルスの回数3回に対応する品質異常の程度を告知するようにしても良い。

【0037】図2(c)に示す品質監視装置本体100においては、ピーク値検出部107は、比較処理部103から「Hi」信号が3回出力されるので、夫々のパルス発生時の絶対値処理部101の出力のピーク値PK1ないしPK3を検出し、告知手段110に異常発生信号及びピーク値PK1ないしPK3を伝える信号を送送する。告知手段110は、品質異常の発生及び前記ピーク値PK1ないしPK3に対応する品質異常の強弱の程度を、音声あるいは表示により告知する。

【0038】図4は、図2(d)の各処理部の信号波形を概念的に示した図である。図4は、具体的には、図1に示す品質監視構成において、拡張時に接続部31bで

品質異常が発生した場合の品質監視装置本体100の各部で出力される波形を示したものである。(a)はAEセンサ10の出力信号を示し、その波形は図3(a)に等しい。(b)は絶対値処理部101の出力信号を示し、その波形は図3(b)に等しい。(c)は包絡線検波部106の出力波形を示している。

【0039】図2の(d)の構成を有する品質監視装置本体100は、図4に示す信号に基づき、次のように品質異常を検出する。比較処理部103及びパルス幅判定部108により包絡線強度の推移を判定し、該包絡線強度が前記異常判定基準値Th1よりも大きい時間(比較処理部103が前記高値発生信号を出力する時間であり、図においてTで示される。)が所定の時間よりも長い場合に、告知手段110に異常発生信号及び前記時間Tを伝える信号を送送する。告知手段110は、品質異常の発生及び前記時間Tに対応する品質異常の強弱の程度を、音声あるいは表示により告知する。

【0040】図5は、図2(a)～(d)に示した鋼管品質監視装置以外の処理構成例を示す制御ブロック図である。AEセンサ10は、前記長尺管30に着設され、長尺管30の表面の振動を信号に変換し出力する。絶対値処理部101は、AEセンサ10の出力信号の直流分を除去した信号の絶対値を増幅処理部105及び包絡線検波部106に出力する。

【0041】増幅処理部105は絶対値処理部101の出力を増幅する部分であるが、その際に、AEセンサに届く弾性波の減衰を補正するために、包絡線検波部106の出力に基づいて、該増幅度を任意の時刻tの該包絡線強度Atに反比例する様にしている。従って、拡張初期の時刻tsの包絡線の強度Asを基準として、監視時刻tの増幅度は、 $As/At$ に設定する。

【0042】包絡線検波部106は、絶対値処理部101の出力信号の各極大値を結ぶ包絡線に所定の処理をした信号を出力し、増幅処理部105に伝達する。ここでは、後に詳述するように、母体となる鋼管30a、30b、30c・・・の拡張時であり異常が発生していない時のAEセンサ出力の振幅を前記増幅度補正の指標とするように、包絡線を処理して増幅処理部105に出力する。

【0043】異常判定基準値設定部102は、増幅処理部105の出力信号の振幅の大きさを判断するための閾値である異常判定基準値Th2を設定する部分である。異常判定基準値設定部102は該長尺管30の拡張加工を始めた初期の時刻tsの包絡線検波部106の出力の振幅Asに予め設定した係数k2(但し、 $k2 > 1$ )を乗じた値を自動的に設定する。

【0044】前記比較処理部103は、増幅処理部105から入力される信号を前記異常判定基準値Th2と比較して、増幅処理部105の信号が異常判定基準値Th2を超えた場合に高値発生信号を出力する。告知手段1

10は、前記高値発生信号が入力されたときに、品質異常が発生した旨を音声或いは表示によって操作者に通知する。

【0045】図6及び図7は、図5に示す各処理構成部の出力を概念的に示した波形図である。具体的には、図1に示す構成で長尺管30の拡張を行なう、接合部32bでひび割れが発生した場合における、図5に示す処理構成の各部の出力波形図である。

【0046】図6(a)に示す信号は、AEセンサ10が長尺管の振動を信号化したものである。この波形は、図3(a)に示す波形と同じであり、全く同様に推移する。即ち、鋼管30aの拡張を行なう時刻t0からt1までは比較的小さい振幅の信号が出力され、接合部31aの拡張をする時刻t1からt2の間は、時刻t0からt1よりも小さい振幅の信号波形を出力する。

【0047】続いて、鋼管30bの拡張を行なう時刻t2からt3までの時間には、前記時刻t0からt1までの時間と同様に、AEセンサ10は比較的小さい振幅の信号波形を出力し、接合部31bの拡張中でありひび割れが発生する時刻t3からt4の間には、比較的大きな振幅の信号波形を出力する。以降、鋼管30cの拡張を行なう時刻t4からt5の間には比較的小さい振幅の信号波形を、図示しないその次の接合部を拡張する時刻t5からt6の間は更に小さい振幅の信号波形を出力する。

【0048】図6(b)に示す波形は、絶対値処理部101の出力信号であり、AEセンサ10の出力信号の直流分を除去した信号を絶対値化したものである。図6(c)に実線で示す波形は、包絡線検波部106の出力信号であり、絶対値処理部101の出力の包絡線を次のように処理したものである。

【0049】即ち、時刻t1から時刻t2、時刻t3から時刻t4及び時刻t5からt6の間は、長尺管の接続部31a、31b、31c・・・の拡張を行なっている時間又は異常が発生している時間の該包絡線は図6

(c)に破線で示す波形になるが、これらの時間については該破線で示す波形を出力せず、その前、後又は前後の時間の包絡線強度の変化から補間した値(図中実線で示す)を該当該時刻の包絡線強度Atとして出力することにする。

【0050】例えば、前記基準の包絡線の推移から求めた予測値と実際の計測値との差又は比が所定の範囲を超えた場合には、該実測値の代わりに該予測値をもちいるようにすればよい。このようにすれば、接続部の拡張時及び品質異常発生時の包絡線強度は母体の鋼管の拡張時の包絡線強度の推移から予測される値を大きく外れるので、これらの時刻の包絡線強度の代わりに前記予測値が使用される。

【0051】図7(a)は、増幅処理部105の出力信号である。この出力は、増幅処理部105が、AEセン

サに届く弾性波の減衰を補正するために、図6(c)に実線で示す包絡線検波部出力の強度に反比例する増幅度で、絶対値処理部101が出力する図6(b)に示す信号を増幅した結果である。図からもわかるように、増幅処理部105は絶対値処理部101の信号を増幅する度合を、拡張中の部位からAEセンサの距離が離れるに応じて高め、拡張による弾性波の減衰を適確に補正して出力する。

【0052】図7(b)は比較処理部103の出力信号を示す。比較処理部103は増幅処理部の出力が前記異常判定基準値Th2を超えると「Hi」信号を出力するので、時刻t3から時刻t4の時間に、高値発生信号であるパルス信号P1乃至P3を出力する。告知手段110は、該高値発生信号を受けて、品質異常の発生を音声又は表示により通知する。

【0053】更に、前記比較回路部103と前記告知手段110との間に、パルス計数処理部を設け、比較処理部103からの前記高値発生信号の回数を計数し、その回数を告知手段110に伝え、告知手段110は品質異常発生の際及び高値発生信号の回数に応じた品質異常の程度を告知するようにしてもよい。

【0054】一方、前記比較回路103からの高値発生信号が出力されたときに、その直後の増幅回路出力の極大値を検出し、その値を告知手段に伝えるピーク値検出部を設け、告知手段110は品質異常発生の際及び該ピーク値の大きさに応じた品質異常の程度を告知するようにしてもよい。

【0055】図8は、鋼管を実際に拡張してひび割れが発生したときの各処理部の出力波形図である。具体的には、図1及び図2(a)に記載の構成によって、本発明による品質監視を実際に行なった場合の出力波形図である。(a)において、時刻t1前後、時刻t2前後、時刻t3前後に発生する大きな振幅の出力波形は、これらの時刻に、ひび割れが発生したために生じたものである。

【0056】図からもわかるように、前記異常判定基準値設定部102が、前記異常判定基準値Th1を拡張初期の時刻tsにおけるAEセンサの振幅Asの5倍の値に設定すると、比較処理部103は(b)に示すように前記高値発生信号であるパルス信号を時刻t1付近に1回、時刻t2付近に2回、時刻t3に3回発生する。従って、告知手段110は、これらの時刻t1、t2又はt3に異常発生を旨を告知する。

【0057】本発明は、前記した実施の形態に何ら限定されるものではなく、本発明の趣旨を逸脱しない範囲で種々の改変が可能である。例えば、監視対象となる鋼管は接合部を有するものに限られないことは、言うまでもない。AEセンサの取付位置は鋼管の側面に限られず、端面に取り付けてもよい。また、前記実施の形態では、拡張マンドレルをテーパー部分を有する拡張マンドレルと

したが、これに限られるわけではなく、例えば、マンドレルの外側面に拡張ローラを有し、該拡張ローラにより鋼管内壁を半径方向外方に押し広げて拡張を行なう構成の拡張マンドレルとしても良い。

【0058】一方、前記異常判定基準値の設定についても実施の形態で例示した処理に限られず、異常なく拡張が行なわれている時の判定対象となる信号の振幅と品質異常が発生した時の判定対象となる信号の振幅との間の値になるように設定すればよい。更に、前記実施の形態において、アナログ信号処理により行なっている処理を、デジタル信号処理により行なうようにしてもよい。例えば、絶対値処理部101或いは増幅処理部105の後にA/Dコンバータを設けてその出力をデジタル信号に変換し、以降の処理をデジタル信号処理により行なうようにしてもよい。

【0059】

【発明の効果】本発明の請求項1に記載の拡張時の品質監視方法によれば、拡張マンドレルが移動して拡張をするときには、常に拡張部位で振動が発生しており、鋼管に品質異常が発生した際には、AEセンサ信号振幅がその前後の時刻の振幅よりも大きくなることを利用したものであり、品質監視のために特別に励振装置、照射装置等を設けることなく拡張時の品質異常の発生を判定することが可能であるという効果を有する。

【0060】また、かかる拡張装置が移動及び拡張するときに発生する振動は、拡張している部位から離れた位置にあるAEセンサまで鋼管を伝搬して届くので、監視装置全体が一定の場所に静止した状態で拡張時の品質監視を行なうことが可能であり、かつ、長尺の鋼管の拡張時の品質監視が可能であるという効果を有する。更に、該振動が伝搬する速度は非常に速いので、拡張によって例えばひび割れ等の品質異常が発生したときには、発生とほぼ同時に品質異常の発生又はその品質異常の程度を検出することが可能である。

【0061】更に、請求項2に記載の拡張時の品質監視方法によれば、請求項1に記載の品質監視方法の効果に加えて、品質監視のために特別に励振装置、照射装置等を設ける必要がなく、監視装置全体が一定の場所に静止した状態で、品質異常の発生とほぼ同時に、品質異常の程度を判定することができるという効果を奏する。

【0062】また、請求項3に示す拡張時の品質監視方法によれば、AEセンサ信号の振幅の連続的な減少に応じてAEセンサの増幅の度合を高め、AEセンサの振幅の連続的な増加に応じてAEセンサ信号の増幅の度合を低下させるようにしたので、拡張によって生じる弾性波がAEセンサに届くまでの減衰を高い精度で補正することができ、該AEセンサ信号を用いて行なう処理の確実性及び信頼性を高めることができるという効果を有する。

【0063】例えば、拡張マンドレルがAEセンサから

離れている場合にはAEセンサ信号の低下が補正されるので、より長尺の鋼管においても確実性の高い品質異常の発生判定及び品質異常の程度の判定が可能になる。また、伝搬距離の変動によるAEセンサ信号振幅の変動が小さくなり、品質異常の発生判定及び品質異常の程度の判定の感度が安定するので、これらの判定の信頼性を高めた拡張時の品質監視方法が提供されることになる。

【図面の簡単な説明】

【図1】本発明に係る鋼管の拡張時の品質監視方法の概念を説明するために示した概略構成図である。

【図2】本発明に適用される鋼管品質監視装置の信号処理構成例を示す制御ブロック図である。

【図3】図2(a)、(b)及び(c)に共通する各処理部の信号波形を概念的に示した図であり、(a)はAEセンサの出力信号、(b)は絶対値処理部の出力信号、(c)は比較処理部の出力信号を示す波形図である。

【図4】図2(d)の各処理部の信号波形を概念的に示した図であり、(a)はAEセンサの出力信号、(b)は絶対値処理部の出力信号、(c)は包絡線検波部の出力信号を示す波形図である。

【図5】図2(a)～(d)に示した鋼管品質監視装置以外の処理構成例を示す制御ブロック図である。

【図6】図5に示す鋼管品質監視装置における各処理構成部の出力を概念的に示した波形図であり、(a)はAEセンサの出力信号、(b)は絶対値処理部の出力信号、(c)は包絡線検波部の出力信号を示す波形図である。

【図7】図5に示す鋼管品質監視装置における各処理構成部の出力を概念的に示した波形図であり、(a)は増幅処理部の出力信号、(b)は比較処理部の出力信号を示す波形図である。

【図8】鋼管を実際に拡張してひび割れが発生したときの各処理部の出力波形図であり、(a)は絶対値処理部の出力波形図、(b)は比較処理部の出力波形図である。

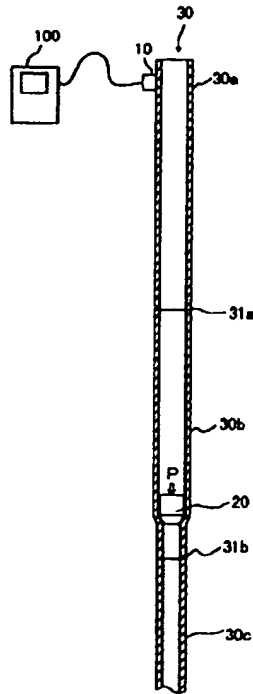
【符号の説明】

- 10 AEセンサ
- 20 拡張マンドレル
- 30 長尺管
- 30a、30b、30c、・・・ 鋼管
- 31a、31b、・・・ 接合部
- 100 品質監視装置本体
- 101 絶対値処理部
- 102 異常判定基準値設定部
- 103 比較処理部
- 104 バルス計数部
- 105 増幅処理部
- 106 包絡線検波部

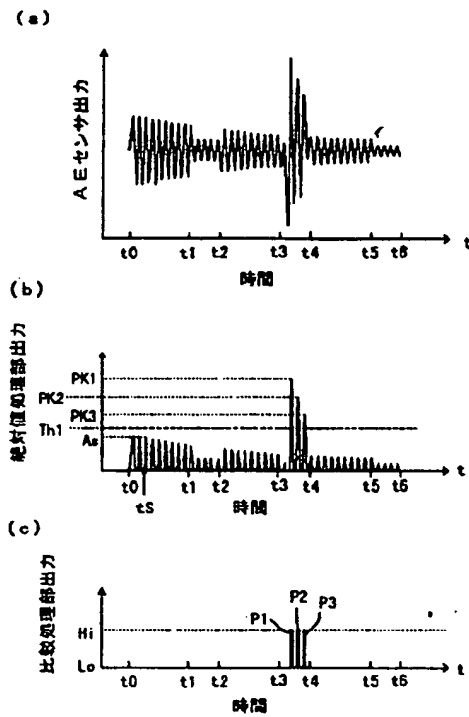
107 ピーク値検出部  
108 パルス幅判定部

110 告知手段

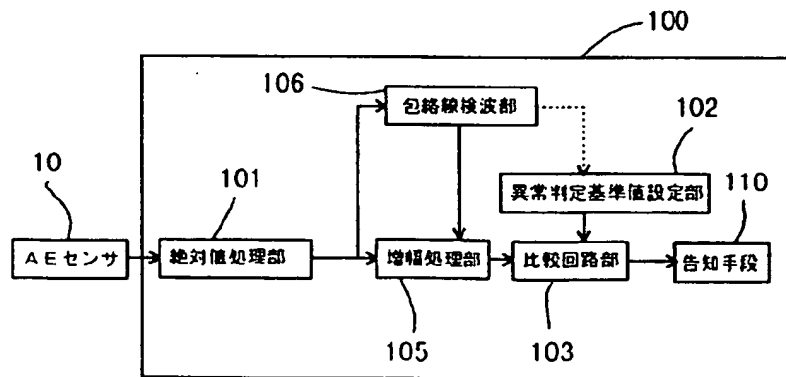
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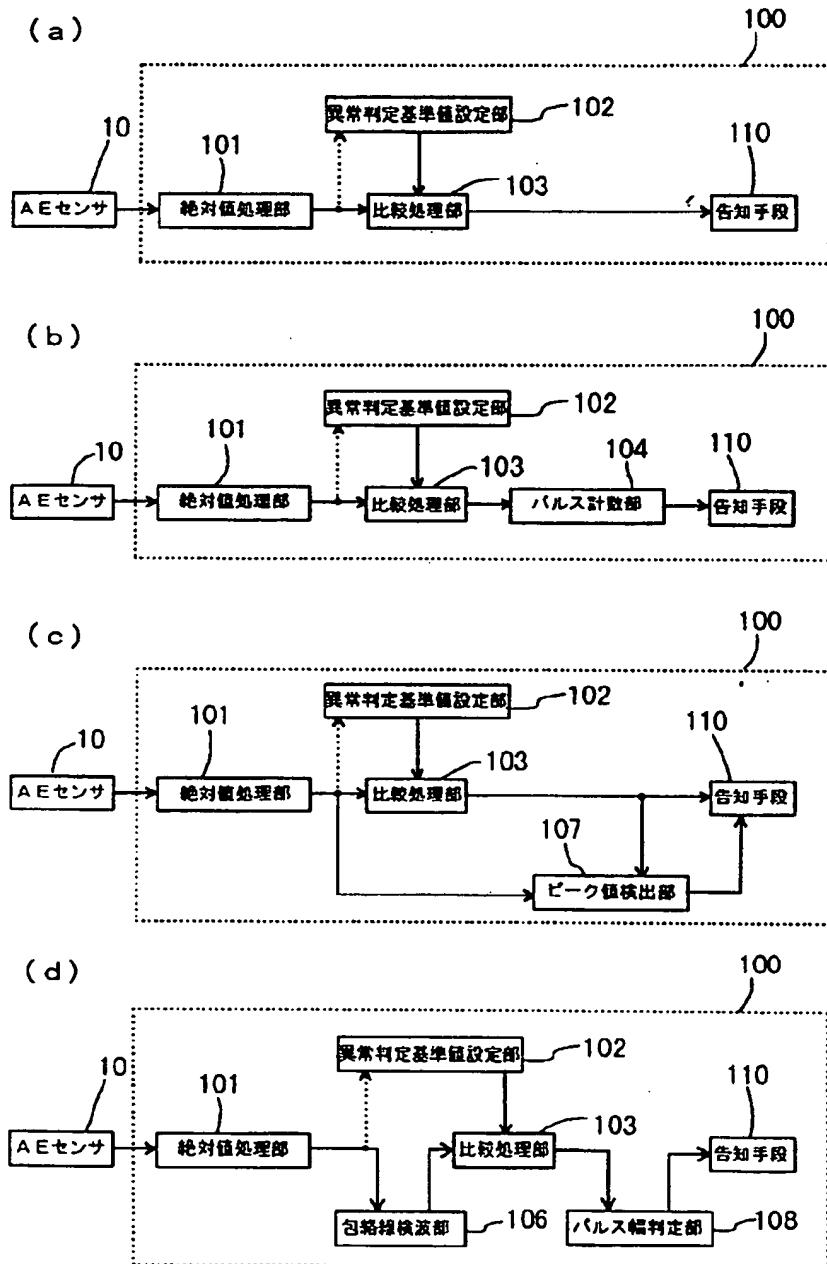
【図3】



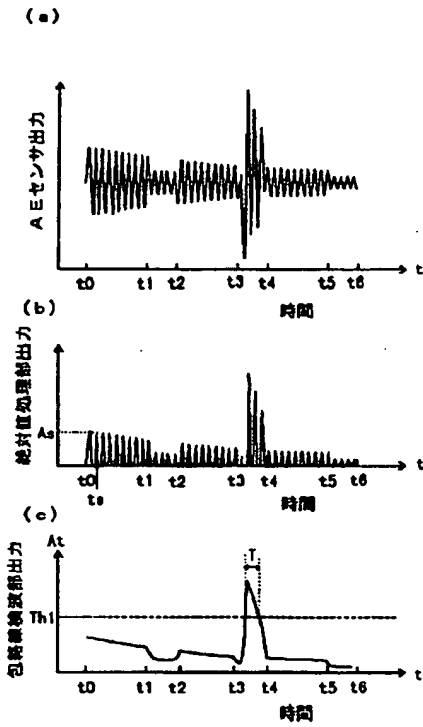
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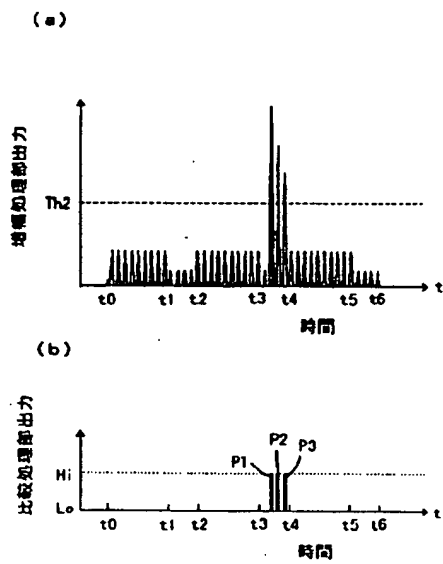
【図2】



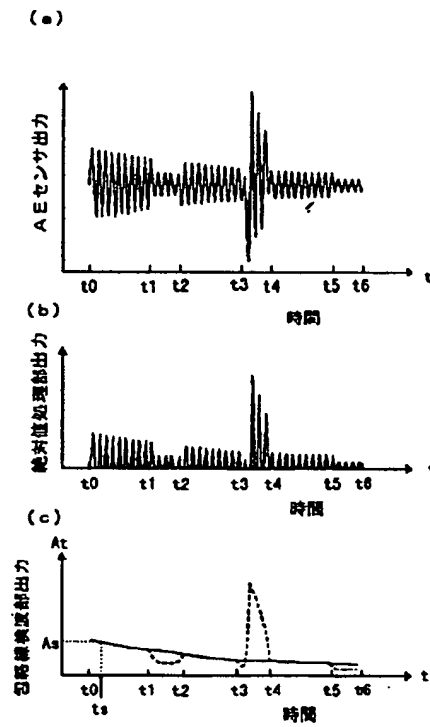
【図4】



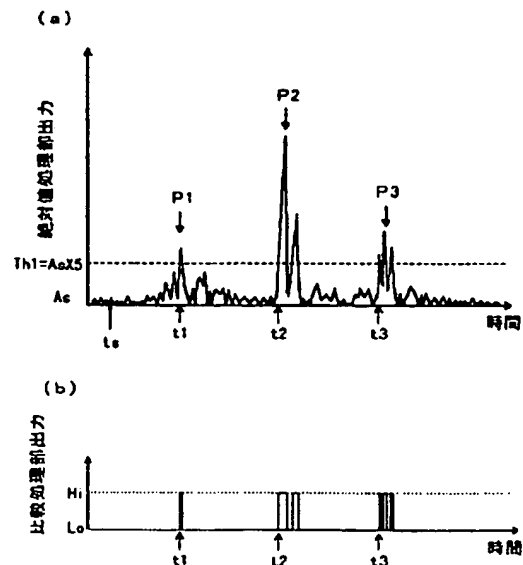
【図7】



【図6】



【図8】



フロントページの続き

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(71) Applicant:	Daido Steel Co., Ltd. (000003713) 1-11-18 Nishiki, Naka-ku, Nagoya, Aichi Prefecture
(72) Inventor:	Ryuzo Yamada 48-1 Nishikatada, Okusa, Chita, Aichi Prefecture
(72) Inventor:	Koji Horio 18 Minamishikamochi, Kagiya-machi, Tokai, Aichi Prefecture
(72) Inventor:	Takao Hi Yamizu Yagoto San Haitzu 501 2-311 Omoteyama, Tenpaku-ku, Nagoya, Aichi Prefecture
(74) Agent:	Noboru Ueno, Patent Attorney (100095669) (and 1 other)

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(54) {Title of the Invention} Quality Inspection Method for Use During Tube Expansion

(57) {Summary}  
{Problem}

To offer a quality inspection method for expanded tubes whereby the occurrence of quality aberration or the degree of quality aberration can be determined at the time of expansion of the steel tube, and whereby remote observation is possible.

{Solution} An AE sensor 10, which detects steel tube vibrations during tube expansion occurring as a tube expansion mandrel 20 moves through the interior of a steel tube 30, is situated against the steel tube. Increases in the AE sensor signal amplitude, the number of increases in the AE sensor signal amplitude or the time over which the increase in AE sensor signal amplitude occurs is detected, and the occurrence of quality aberration or the degree of quality aberration in the aforementioned steel tube is determined on the basis of the detected signals.

[see source for diagram]

{Scope of Patent Claims}

{Claim 1} A quality inspection method for use during tube expansion, characterized in that an AE sensor for detecting vibrations in a steel tube during tube expansion of said steel tube is situated against the steel tube, and when tube expansion occurs as a tube expansion mandrel moves through the interior of the steel tube, increases in the AE sensor signal amplitude, the number of increases in the AE sensor signal amplitude or the time over which the increase in AE sensor signal amplitude occurs is detected, and the occurrence of quality aberration in the aforementioned steel tube is determined on the basis of the detected signals.

{Claim 2} The quality inspection method for use during tube expansion according to Claim 1, characterized in that the degree of the quality aberration in the steel tube is determined based on the magnitude of the AE sensor signal amplitude, the number of increases in AE sensor signal amplitude or the time of increase in AE sensor signal amplitude.

{Claim 3} The quality inspection method for use during tube expansion described in Claim 1 or 2, characterized in that the AE sensor signal that is detected during tube expansion is amplified as a tube expansion mandrel moves through the interior of a steel tube, and the level of the aforementioned amplification is increased in accordance with a continual decrease in AE sensor signal amplitude, or the level of the aforementioned amplification is decreased in accordance with a continual increase in AE sensor amplitude.

{Detailed Description of the Invention}

{0001}

{Technological Field of the Invention} The present invention relates to a quality inspection method used during tube expansion. In particular, the invention is a quality inspection method used during tube expansion that is appropriate for inspecting quality aberrations such as cracking or pinholes generated in the joints of long steel tubes, etc., during the expansion of steel tubes.

{0002}

{Prior Art} In the past, the tube expansion of long tubes formed from steel has been carried out using tube expansion mandrels. As shown in Figure 1, this process involves the insertion of a tube expansion mandrel 20 into one of the open ends of a long tube 30, applying a specified weight P in order to insert the tube expansion mandrel 20 into the long tube 30, and pushing the mandrel across the inner wall of the long tube 30 towards the other end, thus performing tube expansion.

{0003} However, there are cases where quality aberrations such as cracks are produced in steel tubes during the tube expansion process. In particular, with tube expansion in steel tubes having mechanical joints or welded regions produced by welding or diffusion welding, quality aberrations readily occur in welded regions. In order to detect these quality aberrations, non-destructive inspections have been traditionally carried out. For example, ultrasonic defect diagnostic methods have been used wherein ultrasound is made to impinge upon the body to be inspected, and internal defects are found based on differences in reflected waves at end surfaces and defect surfaces. In addition, x-ray defect diagnostic methods have been used in which x-rays are made to impinge upon the body to be inspected, and the transmitted radiation is then used to sensitize film, so that the defects can be detected from the photosensitive image thereupon.

{0004} However, in carrying out these inspection methods, there is the problem that at least part of the detection device must be positioned in the region that is to be inspected, and this creates problems that are exacerbated as the length of the tube increases. In addition, there is the problem these inspection methods cannot be carried out on-site during the tube expansion operation, so they must be carried out after completion of tube expansion, at least in the region that is to be inspected. Specifically, with conventional inspection methods, inspection must be carried out with at least part of the inspection device located in the region to be inspected after completion of tube expansion.

{0005} On the other hand, when installing oil well pipes for drawing oil, etc., out of the ground, technologies are known in which tube expansion is carried out by inserting a steel tube with a comparatively small diameter into the ground, and then inserting a tube expansion mandrel, etc., using high downward compressive force, which thereby reduces equipment installation costs. In order to

inspect expanded steel tubes using this conventional method, it is difficult to situate the inspection device at the outer wall surface of the steel tube, and is also difficult to move the inspection device in the lengthwise direction along the outer wall of the steel tube because the tube has been laid underground. Consequently, it has been necessary to inspect the tube by moving the inspection device long the interior of the steel tube. However, the tube diameter is small even after tube expansion, and the total length of the tube can be as long as several kilometers, so there have been extremely difficult problems with quality aberration inspection over the entire length of a steel tube using conventional methods.

{0006}

{Problems to be Solved by the Invention} The problem to be solved by the present invention is that of offering a quality inspection method used at the time of tube expansion, whereby quality aberrations in steel tubes can be evaluated with the inspection device in a stationary condition during the tube expansion process for the steel tube, whereby an occurrence or degree of quality aberration can be determined at a site that is removed from the quality inspection device, and whereby quality aberrations in said steel tube can be detected almost simultaneous to their occurrence.

{0007}

{Means for Solving the Problems} The gist of the present invention used in order to solve these problems relates to a quality inspection method used during tube expansion wherein an AE sensor for detecting vibrations in a steel tube during tube expansion of said steel tube is situated against the steel tube, and when tube expansion occurs as a tube expansion mandrel moves through the interior of the steel tube, increases in the AE sensor signal amplitude, the number of increases in the AE sensor signal amplitude, or the time over which the increase in AE sensor signal amplitude occurs is detected, and the occurrence of quality aberration in the aforementioned steel tube is determined on the basis of the detected signals.

{0008} By means of the quality inspection method used during tube expansion pertaining to the present invention carried out in this manner, vibrations arising on the interior of a steel tube and on the surface of a steel tube during tube expansion occurring as a tube expansion mandrel passes through the interior of a steel tube are detected by an AE sensor situated on the steel tube, and quality aberration is judged to have occurred when an increase amplitude of the aforementioned AE sensor signal is detected, when the number of increases in amplitude of the aforementioned AE sensor signal reaches a predetermined number, or when the time over which the increase in amplitude of the aforementioned AE sensor signal occurs is longer than a predetermined time.

{0009} In addition, as with the invention described in Claim 2, when the degree of quality aberration of the aforementioned steel tube is to be judged based on the magnitude of the increase in AE sensor signal amplitude, the number of increases of AE sensor signal amplitude, or the time of the increase in AE sensor signal amplitude, detected at the time when the aforementioned quality aberration is determined, the degree of the quality aberration of the aforementioned steel tube can be determined based on the magnitude of the aforementioned AE sensor signal amplitude, the number of increases in the aforementioned AE sensor signal amplitude, or time over which the amplitude of the AE sensor signal has increased.

{0010} In addition, as pertains to the invention of Claim 3, the AE sensor signal detected during tube expansion is amplified at the time of tube expansion as the tube expansion mandrel moves long the interior of the steel tube, and the degree of the aforementioned amplification is increased along with a continual decrease in AE sensor signal amplitude, or the degree of the aforementioned amplification is decreased in accordance with a continual increase in AE sensor amplitude.

{0011} With the quality inspection method used during tube expansion described in Claim 3 of the present invention carried out in this manner, the AE sensor signal detected during tube expansion as the tube expansion mandrel moves along the interior of the steel tube is amplified, and as the damping of vibrations generated by the tube as they are conducted to the AE sensor increases, the degree of the aforementioned amplification is increased, or as the aforementioned damping decreases, the degree of the aforementioned amplification is decreased. By this means, damping occurring with transmission of the vibrations generated by tube expansion to the AE sensor is compensated for, and quality inspection is carried out based on said corrected AE sensor signal.

{0012} Employing the change in degree of amplification in accordance with a continual increase or continual decrease in output amplitude from the AE sensor means that the change in tube expansion amplitude in a region in which the output amplitude of the relatively stable AE sensor changes continually is taken as a reference. For example, this means that the aforementioned amplification level is not made to follow discontinuous change in amplitude, as with changes in AE sensor signal amplitude produced during the occurrence of aberration. By excluding these regions of discontinuous change in this manner, correction is carried out based on the change in AE sensor signal amplitude, so that even if the AE signal amplitude increases or decreases over time during the observation period over which quality aberrations, etc. are generated, the attenuation can be appropriately corrected for without erroneous correction.

{0013}

{Embodiments of the Invention} Desirable embodiments of the present invention are described in detail below in reference to the figures. Figure 1 is a schematic constitutional diagram used for schematically presenting the quality inspection method used during tube expansion of steel tubes pertaining to the present invention. A long tube 30 is shown in cross section. Said long tube 30 is a tube produced by welding relatively short steel tubes 30a, 30b, 30c... at weld regions 31a, 31b... In the figure, only three steel tubes are shown, but these tubes continue downwards.

{0014} The tube expansion mandrel 20 has a cylindrical part and a tapered part as shown in the figures, and a load P is applied from behind (upwards in the figure). As the mandrel travels forward (downwards in the figure), the interior wall of the long tube is pressed outwards in a radial direction due to the aforementioned tapered part, thus expanding the aforementioned long tube 30. The AE sensor 10 is situated in contact with the outer wall of the long tube, and the vibrations at said outer surface are converted into signals as the aforementioned tube expansion is taking place. Said signals are output to an inspection device main unit 100 to which it is connected.

{0015} Figure 2 is a control block diagram showing an example of the signal processing structure in the quality inspection device implemented in the present invention. In the quality inspection device main unit 100 shown in (a), the AE sensor 10 is connected to an absolute value processor 101, and the absolute value processor 101 is connected to a comparative processor 103. An aberration decision standard value setting part 102 is also connected with the comparative processor 103, and the comparative processor 103 is connected to a notification means 110.

{0016} The aforementioned absolute value processor 101 removes the direct current component of the output signal from the AE sensor 10, and outputs signals that have been converted into absolute values. The aforementioned aberration decision standard value setting part 102 is the part where the aberration decision standard value Th1 is set, which is the threshold value for determining the size of the signal amplitude from the AE sensor 10. The aberration decision standard value Th1 should be set at a value that is between the AE sensor signal amplitude when tube expansion is occurring without aberration, and the AE sensor signal amplitude when quality aberrations occur.

{0017} For example, the operator uses a standard value setting knob that is provided in order to set the aberration decision standard value obtained experimentally beforehand in accordance with the type of steel tube that is the subject of tube expansion. In this case, the value is automatically set to a value determined by multiplying the AE sensor signal amplitude  $A_s$  at time  $t_s$  in the initial stage in which the tube expansion process is initially occurring in said long tube 30 by a constant  $k_1$  that has been determined beforehand (where  $k_1 > 1$ ).

{0018} The aforementioned comparative processor 103 compares the signal input from the absolute value processor 101 with the aforementioned aberration decision standard value Th1, and when the signal from the absolute value processor 101 exceeds the aberration decision standard value Th1, a high-value generation signal is output. When the aforementioned high value generation signal is input into the notification means 110, a quality aberration is judged to have occurred, and an indication of this occurrence is sent to the operator by a tone or display.

{0019} In this manner, when quality inspection is to be carried out by the quality inspection device main unit 100 constituted in the manner shown in (a), the direct current component is taken from the signal from the AE sensor 10, and is rectified to obtain an amplitude. When the signal amplitude from

the AE sensor 10 exceeds the aberration decision standard value, a notification is made regarding the occurrence of aberration.

{0020} The quality inspection device unit 100 shown in (b), as can be seen from the figure, has a pulse counting processor 104 between the notification means 110 and the comparative processor 103 constituting the quality inspection device shown in (a) above. The pulse counting processor 104 is connected to the comparative processor 103 and the notification means 110. The number of the aforementioned high value generation signals received from the comparative processor 103 is calculated, and when this number reaches or surpasses the number that has been previously set, a quality aberration occurrence signal is output. In this case, a quality aberration occurrence signal is output when the number of occurrences of high value generation signals is 2 or greater.

{0021} Consequently, when quality inspection is carried out with a quality inspection device unit 100 constituted as indicated in (b), the signal from the AE sensor 10 is removed and rectified, and its amplitude is obtained. When the signal amplitude from the AE sensor 10 exceeds the aberration decision standard value two or more times, notification of an occurrence of quality aberration is made.

{0022} In addition, in this case, the pulse counting processor 104 transmits the number of high value generation signals to the notification means 110 in addition to the aforementioned quality aberration generation signal. The notification means 110 should be constituted in such a manner that notification is made regarding the occurrence of quality aberration, and the degree of quality aberration in accordance with the number of high value generation signals. For example, the device may be constituted so that the number of high value generations itself is made known, but in this case, notification indicating "slight" in regard to the degree of aberration is made when the number is 2 or 3, notification indicating "moderate" is made when the number is 4 or 5, and notification indicating "high" is made when the number is 6 or greater.

{0023} The quality inspection device unit 100 shown in (c) is expanded upon by adding a peak detector 107 to the quality inspection device presented in (a). Output from the absolute value processor 101 and output from the comparative processor 103 is input into the peak value detector 107, and this is linked to the notification means 110. When the aforementioned high value generation signal is output from the aforementioned comparative processor 103, the peak value detector 107 retains the peak value of the output of the absolute value processor 101 at this time, and outputs this value to the aforementioned notification means 110.

{0024} Thus, the notification means 110 reports the degree of quality aberration based on the aforementioned peak value in addition to reporting the occurrence of quality aberration. For example, the magnitude of the peak value itself may be reported, but in this case, notification of a "high", "moderate" or "low" determination is made in regard to the degree of aberration based on the magnitude of the peak value.

{0025} When quality inspection is carried out using the quality inspection device unit 100 constituted as indicated in (c), the signal from the AE sensor 10 is rectified after removing the direct current component, and the amplitude is obtained. When the signal amplitude of the AE sensor 10 exceeds the aberration decision standard value  $Th1$ , sound or display is used in order to present an indication of an occurrence of aberration and the degree of quality aberration based on the peak value of the AE sensor signal amplitude at the time of occurrence of said quality aberration.

{0026} The quality inspection device unit 100 shown in (d) is a unit in which an envelope detector 106 is also included between the absolute value processor 101 and the comparative processor 103 in the quality inspection device presented in (a), and a pulse width discriminator 108 is also provided between the comparative processor 103 and the notification means 110. The aforementioned envelope detector 106 outputs an envelope signal linking each of the maximum values of the output signals of the absolute value processor 101, and this is transmitted to the comparative processor 103. The comparative processor 103 outputs a high value generation signal to the notification means 110 when the output of the envelope detector 106 is larger than the aforementioned aberration decision standard value  $Th1$ . The pulse width discriminator 108 transmits an indication of an aberration occurrence and the length of time for the aforementioned high value generation to the notification means 110 when the time of the aforementioned high value generation signal is longer than a determined time period.

{0027} Thus, the notification means 110 performs notification of a quality aberration occurrence and degree of quality aberration based on the length of the aforementioned high value generation signal. For example, notification may be made as to the length of the aforementioned high value generation signal itself, but in this case, notification is made as to the results of determination based on "high", "moderate" or "low" in regard to the degree of aberration determined based on the length of the aforementioned high value generation signal period.

{0028} When quality inspection is carried out with the quality inspection device unit 100 constituted as shown in (d), the direct current component is removed from the AE sensor 100 signal, and the time for which the envelope intensity of the rectified signal exceeds the aberration decision standard value is calculated. If said time is longer than the determined time period, then sound or display is used in order to make a notification regarding quality aberration and the degree of quality aberration determined based on the time that the envelope intensity exceeded the aberration decision standard value  $Th1$ .

{0029} Figure 3 presents a schematic diagram in which the signal waveform for each of the processors is shown in common for Figure 2a, 2b and 2c. Specifically, Figure 3 shows the waveforms outputs at each part of the quality inspection device unit 100 when a quality aberration has occurred at the connection 31b during tube expansion, for the quality inspection system shown in Figure 1, whereas (a) shows the output signal for the AE sensor 10, (b) shows the output signal for the absolute value processor 101, and (c) shows the output value for the comparative processor 103.

{0030} The waveform shown in (a) will be described in sequence. When the tube expansion process is initiated with advancement of the tube expansion mandrel 20 at time  $t_0$ , vibrations are generated via acoustic emission (AE) arising due to plastic deformation, etc., occurring with tube expansion and vibrations are generated due to friction between the long tube 30 and the tube expansion mandrel 10 as advancement occurs (these vibrations are referred to in combination as "tube expansion vibrations"). When there is no aberration in quality, the tube expansion vibrations give a comparatively weak elastic wave. Consequently, for the period extending from time  $t_0$  to time  $t_1$  during tube expansion of the steel tube 30a, a signal waveform having a comparatively small amplitude is output by the AE sensor 10.

{0031} Next, during the period from time  $t_1$  to time  $t_2$  in which tube expansion of the weld 31a occurs, said weld region 31a has been welded by mechanical joining, diffusion welding or welding, so its hardness is higher than that of the steel tube 30a. As a result, the progress of the tube expansion mandrel 20 slows, and the aforementioned tube expansion vibrations give vibrations of even weaker amplitude. At this time, the AE sensor 10 outputs a signal waveform for vibrations that are smaller from time  $t_0$  to time  $t_1$ . During the time from  $t_2$  to  $t_3$  in which the steel tube 30b expands, the AE sensor 10 outputs a signal waveform with a comparatively weak amplitude as with the time period from time  $t_0$  to  $t_1$  described above.

{0032} When there is a crack generated during tube expansion of the connection 31b, the energy emanates from the crack, and an elastic wave with a comparatively large amplitude is produced. The tube expansion vibrations that include said elastic waves are detected by the AE sensor 10, and during the period from time  $t_3$  to time  $t_4$ , a signal waveform with a comparatively large amplitude is output. Subsequently, as shown in the figure, the AE sensor 10 outputs a signal waveform that has a comparatively small amplitude from time  $t_4$  to time  $t_5$  during tube expansion of the steel tube 31c as shown in the figure. Then a signal waveform with an even smaller amplitude is output from time  $t_5$  to time  $t_6$  during expansion of the next weld region thereof not shown in the figure.

{0033} Meanwhile, the output waveform from the absolute value processor 101 is the absolute value conversion determined after removing the direct current component of the AE sensor output shown in (a), thus producing the waveform shown in (b). In addition, the comparative processor 103 compares the output signal from the aforementioned absolute value processor 101 with the aberration decision standard value  $TH1$  set as described above, and a "Hi" signal is output when the value is larger than said standard value  $TH1$ , whereas a "Lo" signal is output when said value is smaller than said standard value.

{0034} Consequently, when the output signal of the absolute value processor 101 shown in (b) is input, the comparative processor 103 outputs the waveform shown in (c). During the time from time  $t_0$

to time  $t_3$ , the output remains "Lo" because there is no input from the absolute value processor 101 that is higher than the aforementioned aberration decision standard value  $TH_1$ . Next, because a crack is generated in the time period from time  $t_3$  to  $t_4$ , a signal having an amplitude that is larger than the aforementioned aberration decision standard value  $TH_1$  as shown in (b) is input, and pulses P1 to P3 are output during the time period from time  $t_3$  to  $t_4$  in (c). Subsequently, there is no output that is larger than the aforementioned standard value  $TH_1$  during the time period from time  $t_4$  to  $t_6$ , and so the value remains "Lo".

{0035} With the respective quality inspection device units 100 having the constitutions described in (a)-(c) of Figure 2, the following types of processes are carried out based on the output signals shown in (a)-(c) of Figure 3. With the quality inspection device unit 100 shown in Figure 2(a), a "Hi" pulse is output from the comparative processor 103, and an aberration generation signal is output to the notification device 110, so that notification of an occurrence of an aberration is made by the notification means 110.

{0036} With the quality inspection device unit 100 shown in Figure 2(b), the number of pulses output from the comparative processor 103 is 3, and because this corresponds to 2 or more occurrences, notification is made regarding an indication of quality aberration. In addition, notification is also made regarding the degree of quality aberration corresponding to a pulse number of three for the high value signals.

{0037} In the quality inspection device unit 100 shown in Figure 2(c), the peak value detector 107 produces three outputs of "Hi" signals from the comparative processor 103, and so peak values PK1 through PK3 of the absolute value processor 101 output are detected during the pulse generation time. Consequently, an aberration occurrence signal and signals representing the peak values PK1 to PK3 are sent to the notification means 110. The notification means 110 then makes notification, via sound or display, of the occurrence of quality aberration, and the degree of the quality aberration corresponding to the aforementioned peak values PK1 through PK3.

{0038} Figure 4 is a diagram that presents a schematic representation of the signal waveforms for each of the processors in Figure 2(d). Figure 4, specifically, represents the waveform output at each of the parts of the quality inspection device unit 100 when there is a quality aberration at the connection 31b during tube expansion carried out by the quality inspection system presented in Figure 1, whereas (a) represents the output signal of the AE sensor 10, where this waveform is similar to that of Figure 3(a). Here, (b) represents the output signal of the absolute value processor 101, where this waveform is similar to that of Figure 3(b), and (c) represents the output waveform of the envelope detector 106.

{0039} The quality inspection device unit 100 having the constitution of (d) in Figure 2 detects quality aberration in the following manner based on the signals presented in Figure 4. The variation in envelope intensity is determined by the pulse width determination part 108 and the comparative processor 103, and when the time during which said envelope intensity is greater than the aforementioned aberration decision standard value  $Th_1$  (time over which the comparative processor 103 outputs the aforementioned high value generation signal; represented by T in the figure) is longer than the predetermined time, an aberration generation signal and a signal that transmits the aforementioned time T is sent to the notification means 110. The notification means 110 then makes a notification, via sound or display, as to the occurrence of quality aberration, and the degree of quality aberration corresponding to the aforementioned time period T.

{0040} Figure 5 is a control block diagram showing a processing system example that is different from the steel tube quality inspection device presented in Figures 2(a)-(d). The AE sensor 10 is attached to the aforementioned long tube 30, and surface vibrations from the long tube 30 are converted to signals that are output. The absolute value processor 101 removes the direct current component of the AE sensor 10 output signal, and outputs the absolute value of the resulting signal to the amplification processor 105 and envelope detector 106.

{0041} The amplification processor 105 is the part that amplifies the absolute value processor 101 output, and in order to correct for attenuation of the elastic waves reaching the AE sensor at this time, said level of amplification is made such that it is inversely proportional to said envelope intensity at any give time t, based on the output of the envelope detector 106. Consequently, the level of

amplification at inspection time  $t_s$  is set at  $A_s/A_t$  using, as reference, the intensity  $A_s$  of the envelope at time  $t_s$  during the initial tube expansion period.

{0042} The envelope detector 106 outputs a signal produced by carrying out specified processing on the envelope that links each maximum of the output signals from the absolute value processor 101, and this signal is transmitted to the amplification processor 105. As described in detail below, when no aberrations are being generated during tube expansion of the main steel tube bodies 30a, 30b, 30c..., the envelope is processed taking the amplitude of the AE sensor output as an index of the aforementioned amplification level correction. The result is output to the amplification processor 105.

{0043} The aberration decision standard value setting part 102 is the part whereby the aberration decision standard value  $Th2$  is set, which is the threshold value for determining the magnitude of the output signal amplitudes from the amplification processor 105. The aberration decision standard value setting part 102 automatically is set to a value found by multiplying the amplitude  $A_s$  of the output from the envelope detector 106 at time  $t_s$  during the initial period of the tube expansion process of said long tube 30 by a predetermined constant  $k_2$  (where  $k_2 > 1$ ).

{0044} The aforementioned comparative processor 103 compares the signal input from the amplification processor 105 with the aforementioned aberration decision standard value  $Th2$ , and outputs a high value generation signal when the signal of the amplification processor 105 is greater than the aberration decision standard value  $Th2$ . The notification means 110 notifies the operator via sound or display as to the occurrence of quality aberration when the aforementioned high value generation signal has been input.

{0045} Figure 6 and Figure 7 are waveform diagrams that give a schematic presentation of the outputs of each of the constitutive processors shown in Figure 5. Specifically, the figures are output waveform diagrams for each of the constitutive processors shown in Figure 5 when cracks occur in the connection 32b along with tube expansion of a long tube 30 having the constitution shown in Figure 1.

{0046} The signal shown in Figure 6(a) is produced by conversion of the vibrations from the long tube into signals by the AE sensor 10. This waveform is the same as the waveform shown in Figure 3(a) and varies similarly. Specifically, an amplitude signal that is comparatively small is output from time  $t_0$  to time  $t_1$  as tube expansion of the steel tube 30a is occurring, whereas an amplitude signal waveform that is smaller than the waveform from time  $t_0$  to time  $t_1$  is output over the time period from time  $t_1$  to time  $t_2$  during which tube expansion of the weld region 31a occurs.

{0047} Subsequently, over the time period from time  $t_2$  to time  $t_3$  during which tube expansion of the steel tube 30b occurs, the AE sensor 10 outputs a signal waveform with an amplitude that is comparatively weak, as with the waveform output over the time period from  $t_0$  to  $t_1$  above. During the period from time  $t_3$  to  $t_4$  during which cracking occurs during tube expansion in the connection 31b, a signal waveform with a comparatively large amplitude is output. Subsequently, a signal waveform with a comparatively small amplitude is output over the period from time  $t_4$  to  $t_5$  during which tube expansion of the tube 30c occurs. A signal waveform with a small amplitude is again output over the time period from time  $t_5$  to  $t_6$  during which the subsequent weld region is undergoing tube expansion (not shown in the figure).

{0048} The waveform shown in Figure 6(b) is the output signal from the absolute value processor 101, and results from removing the direct current component of the output signal from the AE sensor 10, and performing absolute value conversion. The waveform represented by the solid line in Figure 6(c) is the output signal from the envelope detector 106, and is produced as a result of processing the envelope from the outputs of the absolute value processor 101 in the manner described below.

{0049} Specifically, the periods from time  $t_1$  to time  $t_2$ , time  $t_3$  to time  $t_4$ , and time  $t_5$  to time  $t_6$ , are times when tube expansion is occurring in weld regions 31a, 31b, 31c... of the long tube, or times when aberrations are occurring. The envelopes for these times produce the waveforms represented by the broken lines in Figure 6(c), but the waveforms represented by said broken lines are not output in these time periods. Rather, values interpolated from the change in envelope intensity at a time before, after, or before and after (represented by the solid lines in the figure) are output as the envelope intensity  $A_t$  for said time points.

{0050} For example, when the difference or ratio of the actual calculated value and the predicted value determined from the change in the envelope using the aforementioned standard exceeds a predetermined range, said predicted value is used instead of said actual value. Thus, the envelope intensities during tube expansion in the weld regions and during quality aberration will be far outside the values predicted from the transition of the envelope intensity during tube expansion of the main body of the steel tube, and so the aforementioned predicted values are used instead of the envelope intensity at these times.

{0051} Figure 7(a) shows the output signal from the amplification processor 105. With regard to the output, the amplification processor 105 amplifies the signal shown in Figure 6(b) that is output by the absolute value processor 101 by a degree of amplification that is inversely proportional to the intensity of the envelope detector output represented by the solid line in Figure 6(c) in order to correct for damping of the elastic waves reaching the AE sensor. As is seen in the figure, the degree of amplification of the signal from the absolute value processor 101 is increased by the amplification processor 105 in accordance with the distance of the AE sensor from the site of tube expansion. An output is thus made after correcting for damping of the elastic waves produced by tube expansion.

{0052} Figure 7(b) shows the output signal from the comparative processor 103. The comparative processor 103 outputs a "Hi" signal when the output of the amplification processor exceeds the aforementioned aberration decision standard value  $Th_2$ , and thus outputs pulse signals P1 to P3 which are high value generation signals during the period from time  $t_3$  to  $t_4$ . The notification means 110 receives said high value generation signals, and uses sound or display to make a notification as to the occurrence of quality aberration.

{0053} In addition, a pulse counting processor is provided between the aforementioned comparative circuit part 103 [sic] and the aforementioned notification means 110, whereby the number of the aforementioned high value generation signals from the comparative processor 103 is counted. This number is then transmitted to the notification means 110. The notification means 110, thus renders notification regarding the occurrence of quality aberration and the degree of quality aberration based on the number of the high value generation signals.

{0054} Meanwhile, a peak value detector is provided that detects the maximum value for the amplification circuit output immediately after the point when the high value generation signal is output from the aforementioned comparative circuit 103. The notification means 110 thus renders notification as to the occurrence of quality aberration, and the degree of quality aberration based on the magnitude of said peak value.

{0055} Figure 8 is an output waveform diagram for each of the processors when cracking occurs during actual tube expansion of the steel tube. Specifically, the figure is an output waveform diagram when quality inspection is actually being carried out according to the present invention using the configuration described in Figure 1 and Figure 2(a). In (a), the high-amplitude output waveforms occurring approximately at times  $t_1$ ,  $t_2$  and  $t_3$  are generated due to the occurrence of cracking at these time points.

{0056} As is clear from the figures, when the aforementioned aberration decision standard value  $Th_1$  is set to  $5x$  the value of the amplitude  $A_s$  of the AE sensor at time  $t_s$  in the initial period of tube expansion using the aforementioned aberration decision standard value setting part 102, the comparative processor 103, as shown in (b) generates pulse signals which are the aforementioned high value generation signals, the first being close to time  $t_1$ , the second being close to time  $t_2$  and the third being close to time  $t_3$ . Consequently, the notification means sends notification of aberration occurrences at these time points  $t_1$ ,  $t_2$  and  $t_3$ .

{0057} The present invention is not restricted by the embodiments described above, and various modifications are possible within a range that does not exceed the scope of the invention. For example, it goes without saying that the steel tube that is the subject of inspection is not restricted to one that has weld regions. The site of attachment of the AE sensor is also not restricted to the side surface of the tube, as the sensor may be attached at the end surface. In the embodiments described above, the tube expansion mandrel had a tapered region, but mandrels are not restricted to this type. For example, a tube expansion mandrel can be used that has expanding diameter rollers present on the

outer surface of the mandrel, so that the internal wall of the steel tube is pressed outwards in a radial direction by means of said expanding diameter rollers.

{0058} On the other hand, regarding setting of the aforementioned aberration decision standard value, modes are not restricted to the process represented in the embodiment, and the value may be set to a value that is between the amplitude of the signal determined when normal tube expansion is occurring and the amplitude of the signal determined when quality aberration occurs. In addition, in the aforementioned embodiment, processing performed by analog signal processors can be carried out by means of digital signal processing. For example, an A/D converter can be provided after the absolute value processor 101 or the amplification processor 105 so that their outputs are converted to digital signals, which are then subjected to digital signal processing for subsequent processes.

{0059}

{Effects of the Invention} By means of the quality inspection method used during tube expansion described in Claim 1 of the present invention, as tube expansion occurs with movement of the tube expansion mandrel, vibrations are generated at the site of tube expansion. When quality aberrations are generated in the steel tube, the AE sensor signal amplitude increases relative to the amplitude at previous and subsequent time points. By employing this increase, the invention has the merit of allowing determination regarding an occurrence of quality aberration as tube expansion occurs without installing special irradiation devices or drive devices for quality inspection.

{0060} In addition, vibrations generated by tube expansion and by movement of the tube expansion device are transmitted through the steel tube to an AE sensor that is at a location distant from the site where tube expansion is occurring, so that it is possible to perform quality inspection during tube expansion with the inspection device itself fixed at a specific location. In addition, there is also the merit that quality inspection can be carried out as the long steel tube is undergoing expansion. Because the rate of transmission of said vibrations is extremely fast, when quality aberrations such as cracking occur during tube expansion, it is possible to detect the occurrence of quality aberration and the degree of quality aberration nearly simultaneous to its occurrence.

{0061} Moreover, with the quality inspection method used during tube expansion described in Claim 2, in addition to the merits of the quality inspection method described in Claim 1, there is the merit that the degree of quality aberration can be determined simultaneous to the quality aberration with the inspection device itself fixed at a determined location, without requiring the use of special drive devices or irradiation devices for quality inspection.

{0062} Moreover, with the quality inspection method used during tube expansion described in Claim 3, the degree of amplification of the AE sensor is increased in accordance with a continual decrease in AE sensor signal amplitude, or the degree of amplification of the AE sensor signal is decreased in accordance with a continual increase in AE sensor amplitude. By this means, damping of the elastic waves generated due to tube expansion occurring during the time it takes them to reach the AE sensor can be compensated for with high precision, so that it is possible to increase the reliability and accuracy of processing carried out using said AE sensor signal.

{0063} For example, as the tube expansion mandrel becomes increasingly distant from the AE sensor, the decrease in AE sensor signal is compensated for, and thus even with long steel tubes, it is possible to determine the occurrence of quality aberration and the degree of quality aberration with a high level of accuracy. Moreover, because stable determination of the occurrence of quality aberration and the degree of quality aberration is possible with little fluctuation in AE sensor signal amplitude due to change in transmission distance, a quality inspection method for use during tube expansion is provided that increases the reliability of these determinations.

{Brief Description of the Figures}

{Figure 1} Schematic constitutional diagram that presents a summary of the quality inspection method during tube expansion of steel tubes pertaining to the present invention.

{Figure 2} Control block diagram showing an example of the signal processing system for the steel tube quality inspection device used in the present invention.

{Figure 3} Diagram giving a schematic presentation of the signal waveforms for each of the processors of Figure 2(a), (b) and (c), where (a) is the waveform diagram of the output signal from the

AE sensor, (b) is the waveform diagram of the output signal from the absolute value processor and (c) is the waveform diagram of the output signal from the comparative processor.

{Figure 4} Diagram giving a schematic presentation of the signal waveforms for each of the processors for Figure 2(d), where (a) is the waveform diagram of the output signal from the AE sensor, (b) is the waveform diagram of the output signal from the absolute value processor and (c) is the waveform diagram of the output signal from the envelope detector.

{Figure 5} Control block diagram showing an example of a processing system other than that of the steel tube quality inspection device presented in Figure 2(a)-(d).

{Figure 6} Waveform diagrams giving a schematic presentation of the outputs of the constitutive processors for the steel tube quality inspection device shown in Figure 5, where (a) is the waveform diagram of the output signal from the AE sensor, (b) is the waveform diagram of the output signal from the absolute value processor and (c) is the waveform diagram of the output signal from the envelope detector.

{Figure 7} Waveform diagrams giving a schematic presentation of the outputs of the constitutive processors for the steel tube quality inspection device shown in Figure 5, where (a) is the waveform diagram of the output signal from the amplification processor and (b) is the waveform diagram of the output signal from the comparative processor.

{Figure 8} Waveform diagrams for the various processors when cracking occurs during actual tube expansion of a steel tube, where (a) is the output waveform diagram from the absolute value processor amplification processor and (b) is the output waveform diagram from the comparative processor.

{Key}

- 10 AE sensor
- 20 Tube expansion mandrel
- 30 Long tube
- 30a, 30b, 30c... Steel tubes
- 31a, 31b...Weld regions
- 100 Quality inspection device unit
- 101 Absolute value processor
- 102 Aberration decision standard value setting part
- 103 Comparative processor
- 104 Pulse calculator
- 105 Amplification processor
- 106 Envelope detector
- 107 Peak value detector
- 108 Pulse width determination part
- 110 Notification means

[see source for figures]

Figure 1

Figure 3

(a)

AE sensor output

Time

(b)

Absolute value processor output

Time

(c)

Comparative processor output

Time

Figure 5  
[see Key above]

Figure 2  
[see Key above]

Figure 4  
(a)  
AE sensor output  
Time  
(b)  
Absolute value processor output  
Time  
(c)  
Envelope detector output  
Time

Figure 6  
(a)  
AE sensor output  
Time  
(b)  
Absolute value processor output  
Time  
(c)  
Envelope detector output  
Time

Figure 7  
(a)  
Amplification processor output  
Time  
(b)  
Comparative processor output  
Time

Figure 8  
(a)  
Comparative value processor output  
Time  
(b)  
Comparative processor output  
Time

Continued from the front page

F Terms (Reference) [see source for codes]



TRANSPERFECT TRANSLATIONS

### AFFIDAVIT OF ACCURACY

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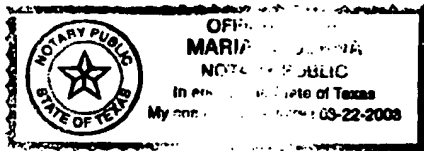
  
Kim Stewart

TransPerfect Translations, Inc.  
3600 One Houston Center  
1221 McKinney  
Houston, TX 77010

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記品質異常を判定した際に検知されるAEセンサ信号の振幅の大きさ、AEセンサ信号の振幅が増大した回数若しくはAEセンサ信号の振幅の増大した時間に基づいて前記鋼管の品質異常の程度を判定するようにすれば、前記AEセンサ信号の振幅の大きさに基づいて前記鋼管の品質異常の程度を判定でき、前記AEセンサ信号の振幅が増大した回数に基づいて前記鋼管の品質異常の程度を判定することができ、若しくは、AEセンサ信号の振幅の増大した時間に基づいて鋼管の品質異常の程度を判定することができる。

【0010】更に、請求項3に記載の発明のように、拡張管マンドレルが鋼管の内部を移動しながら拡張する際に検出されるAEセンサの信号を増幅すると共に、AEセンサ信号の振幅の連続的な減少に応じて前記増幅の度合を高め、AEセンサの振幅の連続的な増加に応じて前記増幅の度合を低下させるようにすると良い。

【0011】このように行なう本発明の請求項3に記載の拡張時の品質監視方法によれば、拡張管マンドレルが鋼管の内部を移動しながら拡張する際に検出されるAEセンサの信号を増幅すると共に、拡張により発生する振動がAEセンサまで伝搬することによって生じる減衰が大きくなると前記増幅の度合を増加させ、前記減衰が低下すると前記増幅の度合を減少させるように調整するので、拡張により発生する振動がAEセンサまで伝搬することによって生じる減衰が補正され、該補正されたAEセンサ信号に基づいて品質監視が行なわれる。

【0012】ここで、増幅の度合の変化をAEセンサ出力振幅の連続的な減少又は連続的な増加に応じて行なうこととしているのは、拡張により発生する振動の大きさが比較的安定しておりAEセンサの出力振幅が連続的に変化する部位の拡張振動を基準とすることを意味し、例えば、異常発生時のAEセンサ信号振幅の変化のように非連続的な振幅変化については前記増幅度を追従させないことを意味する。このように非連続変化部分を除いたAEセンサ信号振幅の変化に基づいて補正をすることにより、品質異常等が発生して監視時刻のAE信号振幅が一時的に増大又は減少しても誤った補正をすることなく、減衰を適確に補正する。

【0013】

【発明の実施の形態】以下に本発明の好適な実施の形態を図面を参照して詳細に説明する。図1は、本発明に係る鋼管の拡張時の品質監視方法の概念を説明するために示した概略構成図である。長尺管30については、断面を示している。該長尺管30は、比較的短い鋼管30a、30b、30c・・・が接合部31a、31b・・・において接合されたものである。図においては、鋼管の3本分しか示されていないが、更に下方に続いている。

【0014】拡張管マンドレル20は図示のようにテーパー部分と円柱部分とを有し、後方（図面においては上方）

から荷重Pを負荷され、前方（図面においては下方）に進行しながら前記テーパー部分により長尺管の内壁面を半径方向外方に押し広げて、前記長尺管30を拡張するものである。AEセンサ10は長尺管の外側面に接触する状態で設置され、前記拡張が行われているときの該外側面の振動を信号に変換するものであり、監視装置本体100に接続されて該信号を出力する。

【0015】図2は、本発明に適用される品質監視装置の信号処理構成例を示す制御ブロック図である。（a）に示す品質監視装置本体100においては、AEセンサ10は絶対値処理部101に接続され、絶対値処理部101は比較処理部103に接続され、異常判定基準値設定部102も比較処理部103に接続され、比較処理部103は告知手段110に接続される。

【0016】前記絶対値処理部101はAEセンサ10の出力信号の直流分を取り除き絶対値化した信号を出力する。前記異常判定基準値設定部102はAEセンサ10の信号振幅の大きさを判断するための閾値である異常判定基準値Th1を設定する部分であり、異常判定基準値Th1は、異常なく拡張が行なわれている時のAEセンサ信号振幅と品質異常が発生したときAEセンサ信号振幅との間の値になるように設定されればよい。

【0017】例えば、基準値設定つまみを設けて拡張対象の鋼管の種類に応じて予め実験的に得られた異常判定基準値を操作者が設定するようにしても良いが、ここでは、該長尺管30の拡張加工を始めた初期段階の時刻t<sub>s</sub>のAEセンサ信号振幅A<sub>s</sub>に予め設定した係数k<sub>1</sub>（但し、k<sub>1</sub>>1）を乗じた値を自動的に設定する様にする。

【0018】前記比較処理部103は、絶対値処理部101から入力される信号を前記異常判定基準値Th1と比較して、絶対値処理部101の信号が異常判定基準値Th1を超えた場合に高値発生信号を出力する。告知手段110は、前記高値発生信号が入力されたときに、品質異常が発生したものと判定し、その旨を音声或いは表示によって操作者に通知する。

【0019】このようにして、（a）に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号は直流分を除去され整流され振幅を取得されて、AEセンサ10の信号振幅が異常判定基準値を超えた場合に異常発生旨が告知される。

【0020】（b）に示す品質監視装置本体100は、図からもわかるように、前記（a）に示す品質監視装置の構成の比較処理部103と告知手段110との間にハルス計数部104が介設されたものである。ハルス計数部104は、比較処理部103及び告知手段110と接続される。そして、比較処理部103から受けた前記高値発生信号の回数を計数し、その回数が予め設定した回数以上になった場合に、品質異常発生信号を出力する。ここでは、高値発生信号の発生回数が2回以上になった

ときに、品質異常発生信号を出力することにする。

【0021】従って、(b)に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号は直流分を除去され整流されてその振幅を取得されて、AEセンサ10の信号振幅が異常判定基準値を超えた回数が2回以上の場合に、品質異常発生旨が告知される。

【0022】更に、この場合に、パルス計数部104は、前記品質異常発生信号に加えて、高値発生信号の回数を告知手段110に伝送し、告知手段110は品質異常発生旨及び高値発生信号の回数に応じた品質異常の程度を告知するように構成しても良い。例えば、高値発生回数そのものを告知するようにしても良いが、ここでは、2回ないし3回の場合には異常の程度が「弱」である旨を、4回ないし5回の場合には異常の程度が「中」である旨を、6回以上場合には異常の程度が「強」である旨を告知するようにする。

【0023】(c)に示す品質監視装置本体100は、(a)に示す品質監視装置にピーク値検出部107を増設したものである。ピーク値検出部107には絶対値処理部101の出力及び比較処理部103の出力が入力されると共に、告知手段110に接続される。ピーク値検出部107は、前記比較処理部103から前記高値発生信号が出力された場合に、そのときの絶対値処理部101の出力のピーク値を保持し、前記告知手段110に出力する。

【0024】そして、告知手段110は、品質異常の発生旨及び前期ピーク値に基づいて品質異常の程度を告知する。例えば、ピーク値の大きさそのものを告知するようにしても良いが、ここでは、ピーク値の大きさにより異常の程度を「強」、「中」又は「弱」に判別し、その判別結果を告知するようにする。

【0025】(c)に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号は直流分を除去され整流されて振幅を取得されて、AEセンサ10の信号振幅が異常判定基準値 $T_h1$ を超えた場合には、異常発生旨と該品質異常が発生したときのAEセンサ信号振幅のピーク値に基づく品質異常の程度とが、音声又は表示によって通知される。

【0026】(d)に示す品質監視装置本体100は、(a)に示す品質監視装置の絶対値処理部101と比較処理部103との間に包絡線検波部106を増設し、比較処理部103と告知手段110との間にパルス幅判定部108を増設したものである。前記包絡線検波部106は、絶対値処理部101の出力信号の各極大値を結ぶ包絡線信号を出力し、比較処理部103に伝送する。比較処理部103は、包絡線検波部106の出力が前記異常判定基準値 $T_h1$ よりも大きい時に高値発生信号を告知手段110に出力する。パルス幅判定部108は前期高値発生信号の時間が所定の時間よりも長いときには、

異常発生旨及び前記高値発生時間の長さを告知手段110に伝送する。

【0027】そして、告知手段110は、品質異常の発生旨及び前記高値発生信号時間の長さに基づいて品質異常の程度を告知する。例えば、前記高値発生信号時間の長さそのものを告知するようにしても良いが、ここでは、前記高値発生信号時間の長さにより異常の程度を「強」、「中」又は「弱」に判別し、その判別結果を告知するようにする。

【0028】(d)に示すように構成される品質監視装置本体100によって品質監視をすれば、AEセンサ10の信号から直流分を除去され整流された信号の包絡線強度が異常判定基準値を超えた時間を計測し、該時間が所定の時間よりも長い場合に、異常発生旨と包絡線強度が異常判定基準値 $T_h1$ を超えた時間に基づく品質異常の程度とが、音声又は表示によって通知される。

【0029】図3は、図2(a)、(b)及び(c)に共通する各処理部の信号波形を概念的に示した図である。図3は、具体的には、図1に示す品質監視構成において、拡張時に接続部31bで品質異常が発生した場合の品質監視装置本体100の各部で出力される波形を示したものであり、(a)はAEセンサ10の出力信号を示し、(b)は絶対値処理部101の出力信号を示し、(c)は比較処理部103の出力信号を示す。

【0030】(a)に示す波形を順に説明する。時刻 $t_0$ に拡張マンドレル20の進行によって拡張加工が開始すると、該進行時の拡張マンドレル10と長尺管30との摩擦による振動及び拡張による塑性変形等によって生じるいわゆるアコースティックエミッション(AE)による振動等(以下、これらをまとめて拡張振動という。)が発生する。この拡張振動は品質異常が発生していない場合には、比較的弱い弾性波である。従って、鋼管30aの拡張中である時刻 $t_0$ から $t_1$ までの時間には、AEセンサ10は比較的小さい振幅の信号波形を出力する。

【0031】次に、接合部31aの拡張をする時刻 $t_1$ から $t_2$ の時間は、該接合部31aは例えばメカジョイント、拡散接合、溶接等により接合されており、その硬度が鋼管30aよりも高いため拡張マンドレル20の進行が遅くなり、前記拡張振動は、更に弱い振幅の振動となるため、この時間はAEセンサ10は時刻 $t_0$ から $t_1$ よりも小さい振幅の信号波形を出力する。鋼管30bを拡張する時刻 $t_2$ から $t_3$ までの時間には、前記時刻 $t_0$ から $t_1$ までの時間と同様に、AEセンサ10は比較的弱い振幅の信号波形を出力する。

【0032】そして、次の接合部31bの拡張中にひび割れが発生すると、その破壊によりエネルギーが発散され比較的大きな振幅の弾性波が生じる。AEセンサ10は該弾性波を含む拡張振動を検出して、時刻 $t_3$ から $t_4$ の時間には、比較的大きな振幅の信号波形を出力す

る。以降、図からわかるようにAEセンサ10は、鋼管31cを拡張する時刻t4からt5の時間には比較的小振幅の信号波形を、図示しないその次の接合部を拡張する時刻t5からt6の時間は更に小さい振幅の信号波形を出力する。

【0033】一方、絶対値処理部101の出力波形は、(a)に示すAEセンサ出力の直流分を除去し絶対値化したものであり、(b)に示す如き波形となる。また、比較処理部103は、前記絶対値処理部101の出力信号を前記のように設定された異常判定基準値Th1と比較して、該基準値Th1よりも大きいときには「Hi」を出力し、該基準値よりも小さいときには「Lo」を出力する。

【0034】従って、比較処理部103は、(b)に示す絶対値処理部101の出力信号が入力されると、

(c)に示す波形を出力する。時刻t0からt3の時間は、絶対値処理部101からは前記異常判定基準値Th1よりも大きな入力がないので出力は「Lo」のままである。次に、前記のように時刻t3からt4の時間にひび割れが発生するので、(b)に示すように、前記異常判定基準値Th1よりも大きな振幅の信号が入力され、

(c)において時刻t3からt4の時間に、パルスP1からP3を出力する。続いて、時刻t4からt6の時間は、前記基準値Th1よりも大きな入力がないので、再び「Lo」のままである。

【0035】図2の(a)ないし(c)の構成を有する品質監視装置本体100の夫々は、これらの図3(a)ないし(c)に示す出力信号に基づいて、次のように処理をする。図2(a)に示す品質監視装置本体100は、比較処理部103から「Hi」のパルスが出力されたので、告知手段110へ異常発生信号を発生し、告知手段110が異常の発生を告知する。

【0036】図2(b)に示す品質監視装置本体100は、比較処理部103から出力されるパルスの回数が3回であり、2回以上に該当するので品質異常発生を告知する。また、高値発生信号であるパルスの回数の3回に対応する品質異常の程度を告知するようにしても良い。

【0037】図2(c)に示す品質監視装置本体100においては、ピーク検出部107は、比較処理部103から「Hi」信号が3回出力されるので、夫々のパルス発生時の絶対値処理部101の出力のピーク値PK1ないしPK3を検出し、告知手段110に異常発生信号及びピーク値PK1ないしPK3を伝える信号を送送する。告知手段110は、品質異常の発生旨及び前記ピーク値PK1ないしPK3に対応する品質異常の強弱の程度を、音声あるいは表示により告知する。

【0038】図4は、図2(d)の各処理部の信号波形を概念的に示した図である。図4は、具体的には、図1に示す品質監視構成において、拡張時に接続部31bで

品質異常が発生した場合の品質監視装置本体100の各部で出力される波形を示したものである。(a)はAEセンサ10の出力信号を示し、その波形は図3(a)に等しい。(b)は絶対値処理部101の出力信号を示し、その波形は図3(b)に等しい。(c)は包絡線検波部106の出力波形を示している。

【0039】図2の(d)の構成を有する品質監視装置本体100は、図4に示す信号に基づき、次のように品質異常を検出する。比較処理部103及びパルス幅判定部108により包絡線強度の推移を判定し、該包絡線強度が前記異常判定基準値Th1よりも大きい時間(比較処理部103が前記高値発生信号を出力する時間であり、図においてTで示される。)が所定の時間よりも長い場合に、告知手段110に異常発生信号及び前記時間Tを伝える信号を送送する。告知手段110は、品質異常の発生旨及び前記時間Tに対応する品質異常の強弱の程度を、音声あるいは表示により告知する。

【0040】図5は、図2(a)～(d)に示した鋼管品質監視装置以外の処理構成例を示す制御ブロック図である。AEセンサ10は、前記長尺管30に着設され、長尺管30の表面の振動を信号に変換し出力する。絶対値処理部101は、AEセンサ10の出力信号の直流分を除去した信号の絶対値を増幅処理部105及び包絡線検波部106に出力する。

【0041】増幅処理部105は絶対値処理部101の出力を増幅する部分であるが、その際に、AEセンサに届く弾性波の減衰を補正するために、包絡線検波部106の出力に基づいて、該増幅度を任意の時刻tの該包絡線強度Atに反比例する様にしている。従って、拡張初期の時刻tsの包絡線の強度Asを基準として、監視時刻tの増幅度は、 $As/At$ に設定する。

【0042】包絡線検波部106は、絶対値処理部101の出力信号の各種大値を結ぶ包絡線に所定の処理をした信号を出力し、増幅処理部105に伝達する。ここでは、後に詳述するように、母体となる鋼管30a、30b、30c・・・の拡張時であり異常が発生していない時のAEセンサ出力の振幅を前記増幅度補正の指標とするように、包絡線を処理して増幅処理部105に出力する。

【0043】異常判定基準値設定部102は、増幅処理部105の出力信号の振幅の大きさを判断するための閾値である異常判定基準値Th2を設定する部分である。異常判定基準値設定部102は該長尺管30の拡張加工を始めた初期の時刻tsの包絡線検波部106の出力の振幅Asに予め設定した係数k2(但し、 $k2 > 1$ )を乗じた値を自動的に設定する。

【0044】前記比較処理部103は、増幅処理部105から入力される信号を前記異常判定基準値Th2と比較して、増幅処理部105の信号が異常判定基準値Th2を超えた場合に高値発生信号を出力する。告知手段1

10は、前記高値発生信号が入力されたときに、品質異常が発生した旨を音声或いは表示によって操作者に通知する。

【0045】図6及び図7は、図5に示す各処理構成部の出力を概念的に示した波形図である。具体的には、図1に示す構成で長尺管30の拡張を行なって、接合部32bでひび割れが発生した場合における、図5に示す処理構成の各部の出力波形図である。

【0046】図6(a)に示す信号は、AEセンサ10が長尺管の振動を信号化したものである。この波形は、図3(a)に示す波形と同じであり、全く同様に推移する。即ち、鋼管30aの拡張を行なう時刻t0からt1までは比較的小さい振幅の信号が出力され、接合部31aの拡張をする時刻t1からt2の間は、時刻t0からt1よりも小さい振幅の信号波形を出力する。

【0047】続いて、鋼管30bの拡張を行なう時刻t2からt3までの間には、前記時刻t0からt1までの時間と同様に、AEセンサ10は比較的小さい振幅の信号波形を出力し、接合部31bの拡張中でありひび割れが発生する時刻t3からt4の間には、比較的大きな振幅の信号波形を出力する。以降、鋼管30cの拡張を行なう時刻t4からt5の間には比較的小さい振幅の信号波形を、図示しないその次の接合部を拡張する時刻t5からt6の間は更に小さい振幅の信号波形を出力する。

【0048】図6(b)に示す波形は、絶対値処理部101の出力信号であり、AEセンサ10の出力信号の直流分を除去した信号を絶対値化したものである。図6(c)に実線で示す波形は、包絡線検波部106の出力信号であり、絶対値処理部101の出力の包絡線を次のように処理したものである。

【0049】即ち、時刻t1から時刻t2、時刻t3から時刻t4及び時刻t5からt6の間は、長尺管の接続部31a、31b、31c・・・の拡張を行なっている時間又は異常が発生している時間の該包絡線は図6

(c)に破線で示す波形になるが、これらの時間については該破線で示す波形を出力せず、その前、後又は前後の時間の包絡線強度の変化から補間した値(図中実線で示す。)を該当該時刻の包絡線強度A<sub>t</sub>として出力することにする。

【0050】例えば、前記基準の包絡線の推移から求めた予測値と実際の計測値との差又は比が所定の範囲を超えた場合には、該実測値の代わりに該予測値をもちいるようにすればよい。このようにすれば、接続部の拡張時及び品質異常発生時の包絡線強度は母体の鋼管の拡張時の包絡線強度の推移から予測される値を大きく外れるので、これらの時刻の包絡線強度の代わりに前記予測値が使用される。

【0051】図7(a)は、増幅処理部105の出力信号である。この出力は、増幅処理部105が、AEセン

サに届く弾性波の減衰を補正するために、図6(c)に実線で示す包絡線検波部出力の強度に反比例する増幅度で、絶対値処理部101が出力する図6(b)に示す信号を増幅した結果である。図からもわかるように、増幅処理部105は絶対値処理部101の信号を増幅する度合を、拡張中の部位からAEセンサの距離が離れるに応じて高め、拡張による弾性波の減衰を適確に補正して出力する。

【0052】図7(b)は比較処理部103の出力信号を示す。比較処理部103は増幅処理部の出力が前記異常判定基準値Th2を超えると「Hi」信号を出力するので、時刻t3から時刻t4の時間に、高値発生信号であるパルス信号P1乃至P3を出力する。告知手段110は、該高値発生信号を受けて、品質異常の発生を音声又は表示により通知する。

【0053】更に、前記比較回路部103と前記告知手段110との間に、パルス計数処理部を設け、比較処理部103からの前記高値発生信号の回数を計数し、その回数を告知手段110に伝え、告知手段110は品質異常発生の際及び高値発生信号の回数に応じた品質異常の程度を告知するようにしてもよい。

【0054】一方、前記比較回路103からの高値発生信号が出力されたときに、その直後の増幅回路出力の極大値を検出し、その値を告知手段に伝えるピーク値検出部を設け、告知手段110は品質異常発生の際及び該ピーク値の大きさに応じた品質異常の程度を告知するようにしてもよい。

【0055】図8は、鋼管を実際に拡張してひび割れが発生したときの各処理部の出力波形図である。具体的には、図1及び図2(a)に記載の構成によって、本発明による品質監視を実際に行なった場合の出力波形図である。(a)において、時刻t1前後、時刻t2前後、時刻t3前後に発生する大きな振幅の出力波形は、これらの時刻に、ひび割れが発生したために生じたものである。

【0056】図からもわかるように、前記異常判定基準値設定部102が、前記異常判定基準値Th1を拡張初期の時刻tsにおけるAEセンサの振幅Asの5倍の値に設定すると、比較処理部103は(b)に示すように前記高値発生信号であるパルス信号を時刻t1付近に1回、時刻t2付近に2回、時刻t3に3回発生する。従って、告知手段110は、これらの時刻t1、t2又はt3に異常発生を旨を告知する。

【0057】本発明は、前記した実施の形態に何ら限定されるものではなく、本発明の趣旨を逸脱しない範囲で種々の改変が可能である。例えば、監視対象となる鋼管は接合部を有するものに限られないことは、言うまでもない。AEセンサの取付位置は鋼管の側面に限られず、端面に取り付けてもよい。また、前記実施の形態では、拡張マンドレルをテーパー部分を有する拡張マンドレルと

したが、これに限られるわけではなく、例えば、マンドレルの外側面に拡張ローラを有し、該拡張ローラにより鋼管内壁を半径方向外方に押し広げて拡張を行なう構成の拡張マンドレルとしても良い。

【0058】一方、前記異常判定基準値の設定についても実施の形態で例示した処理に限られず、異常なく拡張が行なわれている時の判定対象となる信号の振幅と品質異常が発生した時の判定対象となる信号の振幅との間の値になるように設定すればよい。更に、前記実施の形態において、アナログ信号処理により行なっている処理を、デジタル信号処理により行なうようにしてもよい。例えば、絶対値処理部101或いは増幅処理部105の後にA/Dコンバータを設けてその出力をデジタル信号に変換し、以降の処理をデジタル信号処理により行なうようにしてもよい。

【0059】

【発明の効果】本発明の請求項1に記載の拡張時の品質監視方法によれば、拡張マンドレルが移動して拡張をするときには、常に拡張部位で振動が発生しており、鋼管に品質異常が発生した際には、AEセンサ信号振幅がその前後の時刻の振幅よりも大きくなることを利用したものであり、品質監視のために特別に励振装置、照射装置等を設けることなく拡張時の品質異常の発生を判定することが可能であるという効果を有する。

【0060】また、かかる拡張装置が移動及び拡張するときに発生する振動は、拡張している部位から離れた位置にあるAEセンサまで鋼管を伝搬して届くので、監視装置全体が一定の場所に静止した状態で拡張時の品質監視を行なうことが可能であり、かつ、長尺の鋼管の拡張時の品質監視が可能であるという効果を有する。更に、該振動が伝搬する速度は非常に速いので、拡張によって例えばひび割れ等の品質異常が発生したときには、発生とほぼ同時に品質異常の発生又はその品質異常の程度を検出することが可能である。

【0061】更に、請求項2に記載の拡張時の品質監視方法によれば、請求項1に記載の品質監視方法の効果に加えて、品質監視のために特別に励振装置、照射装置等を設ける必要がなく、監視装置全体が一定の場所に静止した状態で、品質異常の発生とほぼ同時に、品質異常の程度を判定することができるという効果を奏する。

【0062】また、請求項3に示す拡張時の品質監視方法によれば、AEセンサ信号の振幅の連続的な減少に応じてAEセンサの増幅の度合を高め、AEセンサの振幅の連続的な増加に応じてAEセンサ信号の増幅の度合を低下させるようにしたので、拡張によって生じる弾性波がAEセンサに届くまでの減衰を高い精度で補正することができ、該AEセンサ信号を用いて行なう処理の確実性及び信頼性を高めることができるという効果を有する。

【0063】例えば、拡張マンドレルがAEセンサから

離れている場合にはAEセンサ信号の低下が補正されるので、より長尺の鋼管においても確実性の高い品質異常の発生判定及び品質異常の程度の判定が可能になる。また、伝搬距離の変動によるAEセンサ信号振幅の変動が小さくなり、品質異常の発生判定及び品質異常の程度の判定の感度が安定するので、これらの判定の信頼性を高めた拡張時の品質監視方法が提供されることになる。

【図面の簡単な説明】

【図1】本発明に係る鋼管の拡張時の品質監視方法の概念を説明するために示した概略構成図である。

【図2】本発明に適用される鋼管品質監視装置の信号処理構成例を示す制御ブロック図である。

【図3】図2(a)、(b)及び(c)に共通する各処理部の信号波形を概念的に示した図であり、(a)はAEセンサの出力信号、(b)は絶対値処理部の出力信号、(c)は比較処理部の出力信号を示す波形図である。

【図4】図2(d)の各処理部の信号波形を概念的に示した図であり、(a)はAEセンサの出力信号、(b)は絶対値処理部の出力信号、(c)は包絡線検波部の出力信号を示す波形図である。

【図5】図2(a)～(d)に示した鋼管品質監視装置以外の処理構成例を示す制御ブロック図である。

【図6】図5に示す鋼管品質監視装置における各処理構成部の出力を概念的に示した波形図であり、(a)はAEセンサの出力信号、(b)は絶対値処理部の出力信号、(c)は包絡線検波部の出力信号を示す波形図である。

【図7】図5に示す鋼管品質監視装置における各処理構成部の出力を概念的に示した波形図であり、(a)は増幅処理部の出力信号、(b)は比較処理部の出力信号を示す波形図である。

【図8】鋼管を実際に拡張してひび割れが発生したときの各処理部の出力波形図であり、(a)は絶対値処理部の出力波形図、(b)は比較処理部の出力波形図である。

【符号の説明】

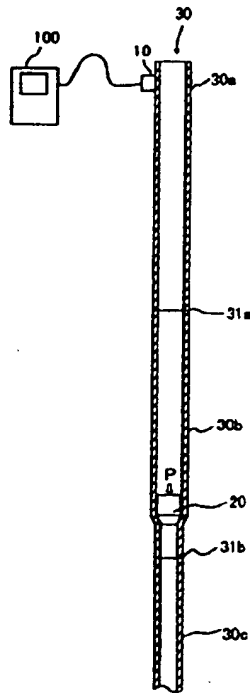
- 10 AEセンサ
- 20 拡張マンドレル
- 30 長尺管
- 30a、30b、30c、・・・ 鋼管
- 31a、31b、・・・ 接合部
- 100 品質監視装置本体
- 101 絶対値処理部
- 102 異常判定基準値設定部
- 103 比較処理部
- 104 バルス計数部
- 105 増幅処理部
- 106 包絡線検波部

107 ピーク検出部

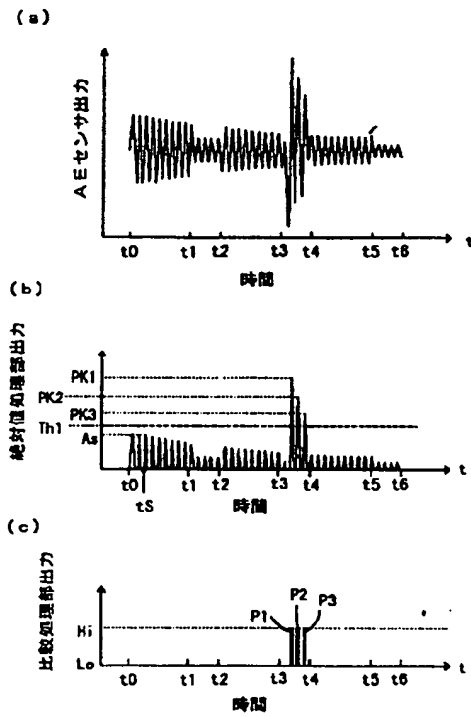
110 告知手段

108 パルス幅判定部

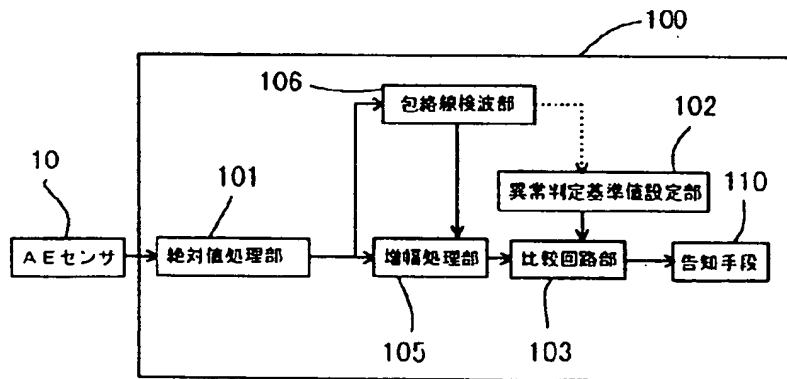
【図1】



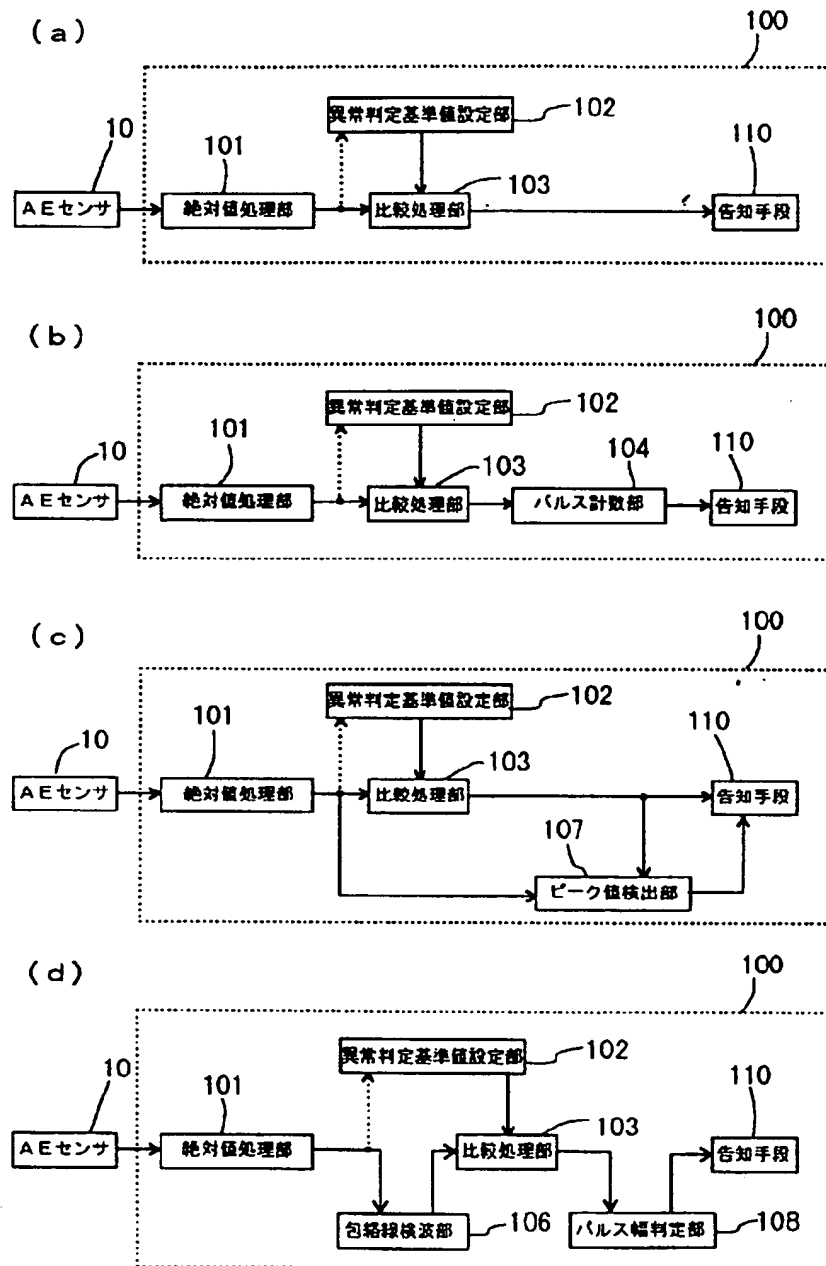
【図3】



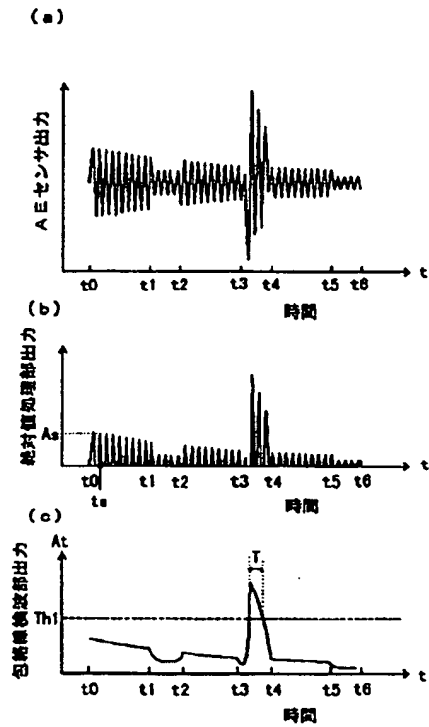
【図5】



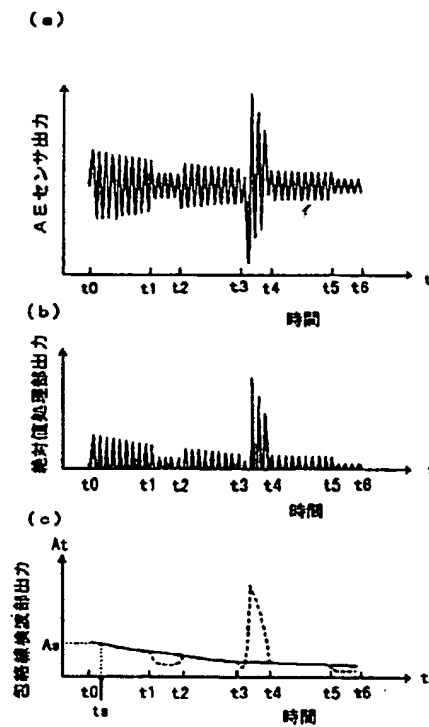
【図2】



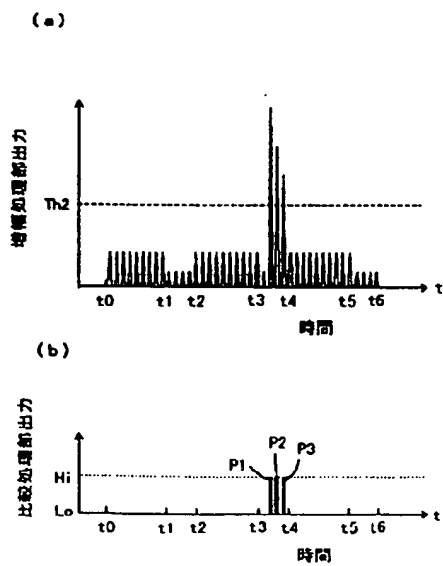
【図4】



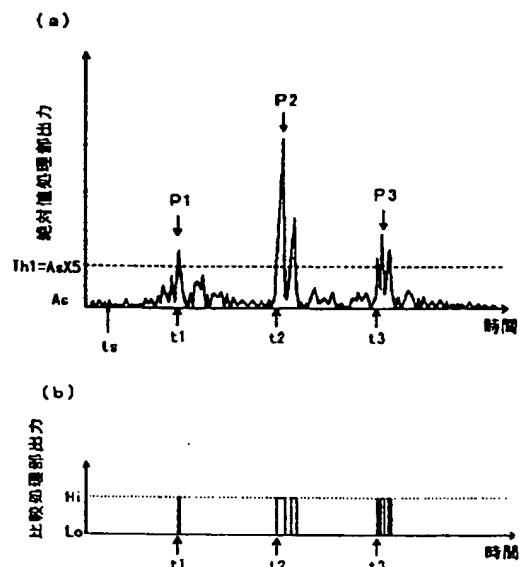
【図6】



【図7】



【図8】



フロントページの続き

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GF10 GG06 GG09 GG24 GG30  
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(71) Applicant: Daido Steel Co., Ltd. (000003713)  
1-11-18 Nishiki, Naka-ku, Nagoya, Aichi Prefecture  
(72) Inventor: Ryuzo Yamada  
48-1 Nishikatada, Okusa, Chita, Aichi Prefecture  
(72) Inventor: Koji Horio  
18 Minamishikamochi, Kagiya-machi, Tokai, Aichi Prefecture  
(72) Inventor: Takao Hiyamizu  
Yagoto San Haitzu 501  
2-311 Omoteyama, Tenpaku-ku, Nagoya, Aichi Prefecture  
(74) Agent: Noboru Ueno, Patent Attorney (100095669) (and 1 other)

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(54) {Title of the Invention} Quality Inspection Method for Use During Tube Expansion

(57) {Summary}  
{Problem}

To offer a quality inspection method for expanded tubes whereby the occurrence of quality aberration or the degree of quality aberration can be determined at the time of expansion of the steel tube, and whereby remote observation is possible.

{Solution} An AE sensor 10, which detects steel tube vibrations during tube expansion occurring as a tube expansion mandrel 20 moves through the interior of a steel tube 30, is situated against the steel tube. Increases in the AE sensor signal amplitude, the number of increases in the AE sensor signal amplitude or the time over which the increase in AE sensor signal amplitude occurs is detected, and the occurrence of quality aberration or the degree of quality aberration in the aforementioned steel tube is determined on the basis of the detected signals.

[see source for diagram]

{Scope of Patent Claims}

{Claim 1} A quality inspection method for use during tube expansion, characterized in that an AE sensor for detecting vibrations in a steel tube during tube expansion of said steel tube is situated against the steel tube, and when tube expansion occurs as a tube expansion mandrel moves through the interior of the steel tube, increases in the AE sensor signal amplitude, the number of increases in the AE sensor signal amplitude or the time over which the increase in AE sensor signal amplitude occurs is detected, and the occurrence of quality aberration in the aforementioned steel tube is determined on the basis of the detected signals.

{Claim 2} The quality inspection method for use during tube expansion according to Claim 1, characterized in that the degree of the quality aberration in the steel tube is determined based on the magnitude of the AE sensor signal amplitude, the number of increases in AE sensor signal amplitude or the time of increase in AE sensor signal amplitude.

{Claim 3} The quality inspection method for use during tube expansion described in Claim 1 or 2, characterized in that the AE sensor signal that is detected during tube expansion is amplified as a tube expansion mandrel moves through the interior of a steel tube, and the level of the aforementioned amplification is increased in accordance with a continual decrease in AE sensor signal amplitude, or the level of the aforementioned amplification is decreased in accordance with a continual increase in AE sensor amplitude.

{Detailed Description of the Invention}

{0001}

{Technological Field of the Invention} The present invention relates to a quality inspection method used during tube expansion. In particular, the invention is a quality inspection method used during tube expansion that is appropriate for inspecting quality aberrations such as cracking or pinholes generated in the joints of long steel tubes, etc., during the expansion of steel tubes.

{0002}

{Prior Art} In the past, the tube expansion of long tubes formed from steel has been carried out using tube expansion mandrels. As shown in Figure 1, this process involves the insertion of a tube expansion mandrel 20 into one of the open ends of a long tube 30, applying a specified weight P in order to insert the tube expansion mandrel 20 into the long tube 30, and pushing the mandrel across the inner wall of the long tube 30 towards the other end, thus performing tube expansion.

{0003} However, there are cases where quality aberrations such as cracks are produced in steel tubes during the tube expansion process. In particular, with tube expansion in steel tubes having mechanical joints or welded regions produced by welding or diffusion welding, quality aberrations readily occur in welded regions. In order to detect these quality aberrations, non-destructive inspections have been traditionally carried out. For example, ultrasonic defect diagnostic methods have been used wherein ultrasound is made to impinge upon the body to be inspected, and internal defects are found based on differences in reflected waves at end surfaces and defect surfaces. In addition, x-ray defect diagnostic methods have been used in which x-rays are made to impinge upon the body to be inspected, and the transmitted radiation is then used to sensitize film, so that the defects can be detected from the photosensitive image thereupon.

{0004} However, in carrying out these inspection methods, there is the problem that at least part of the detection device must be positioned in the region that is to be inspected, and this creates problems that are exacerbated as the length of the tube increases. In addition, there is the problem these inspection methods cannot be carried out on-site during the tube expansion operation, so they must be carried out after completion of tube expansion, at least in the region that is to be inspected. Specifically, with conventional inspection methods, inspection must be carried out with at least part of the inspection device located in the region to be inspected after completion of tube expansion.

{0005} On the other hand, when installing oil well pipes for drawing oil, etc., out of the ground, technologies are known in which tube expansion is carried out by inserting a steel tube with a comparatively small diameter into the ground, and then inserting a tube expansion mandrel, etc., using high downward compressive force, which thereby reduces equipment installation costs. In order to

inspect expanded steel tubes using this conventional method, it is difficult to situate the inspection device at the outer wall surface of the steel tube, and is also difficult to move the inspection device in the lengthwise direction along the outer wall of the steel tube because the tube has been laid underground. Consequently, it has been necessary to inspect the tube by moving the inspection device long the interior of the steel tube. However, the tube diameter is small even after tube expansion, and the total length of the tube can be as long as several kilometers, so there have been extremely difficult problems with quality aberration inspection over the entire length of a steel tube using conventional methods.

{0006}

{Problems to be Solved by the Invention} The problem to be solved by the present invention is that of offering a quality inspection method used at the time of tube expansion, whereby quality aberrations in steel tubes can be evaluated with the inspection device in a stationary condition during the tube expansion process for the steel tube, whereby an occurrence or degree of quality aberration can be determined at a site that is removed from the quality inspection device, and whereby quality aberrations in said steel tube can be detected almost simultaneous to their occurrence.

{0007}

{Means for Solving the Problems} The gist of the present invention used in order to solve these problems relates to a quality inspection method used during tube expansion wherein an AE sensor for detecting vibrations in a steel tube during tube expansion of said steel tube is situated against the steel tube, and when tube expansion occurs as a tube expansion mandrel moves through the interior of the steel tube, increases in the AE sensor signal amplitude, the number of increases in the AE sensor signal amplitude, or the time over which the increase in AE sensor signal amplitude occurs is detected, and the occurrence of quality aberration in the aforementioned steel tube is determined on the basis of the detected signals.

{0008} By means of the quality inspection method used during tube expansion pertaining to the present invention carried out in this manner, vibrations arising on the interior of a steel tube and on the surface of a steel tube during tube expansion occurring as a tube expansion mandrel passes through the interior of a steel tube are detected by an AE sensor situated on the steel tube, and quality aberration is judged to have occurred when an increase amplitude of the aforementioned AE sensor signal is detected, when the number of increases in amplitude of the aforementioned AE sensor signal reaches a predetermined number, or when the time over which the increase in amplitude of the aforementioned AE sensor signal occurs is longer than a predetermined time.

{0009} In addition, as with the invention described in Claim 2, when the degree of quality aberration of the aforementioned steel tube is to be judged based on the magnitude of the increase in AE sensor signal amplitude, the number of increases of AE sensor signal amplitude, or the time of the increase in AE sensor signal amplitude, detected at the time when the aforementioned quality aberration is determined, the degree of the quality aberration of the aforementioned steel tube can be determined based on the magnitude of the aforementioned AE sensor signal amplitude, the number of increases in the aforementioned AE sensor signal amplitude, or time over which the amplitude of the AE sensor signal has increased.

{0010} In addition, as pertains to the invention of Claim 3, the AE sensor signal detected during tube expansion is amplified at the time of tube expansion as the tube expansion mandrel moves long the interior of the steel tube, and the degree of the aforementioned amplification is increased along with a continual decrease in AE sensor signal amplitude, or the degree of the aforementioned amplification is decreased in accordance with a continual increase in AE sensor amplitude.

{0011} With the quality inspection method used during tube expansion described in Claim 3 of the present invention carried out in this manner, the AE sensor signal detected during tube expansion as the tube expansion mandrel moves along the interior of the steel tube is amplified, and as the damping of vibrations generated by the tube as they are conducted to the AE sensor increases, the degree of the aforementioned amplification is increased, or as the aforementioned damping decreases, the degree of the aforementioned amplification is decreased. By this means, damping occurring with transmission of the vibrations generated by tube expansion to the AE sensor is compensated for, and quality inspection is carried out based on said corrected AE sensor signal.

{0012} Employing the change in degree of amplification in accordance with a continual increase or continual decrease in output amplitude from the AE sensor means that the change in tube expansion amplitude in a region in which the output amplitude of the relatively stable AE sensor changes continually is taken as a reference. For example, this means that the aforementioned amplification level is not made to follow discontinuous change in amplitude, as with changes in AE sensor signal amplitude produced during the occurrence of aberration. By excluding these regions of discontinuous change in this manner, correction is carried out based on the change in AE sensor signal amplitude, so that even if the AE signal amplitude increases or decreases over time during the observation period over which quality aberrations, etc. are generated, the attenuation can be appropriately corrected for without erroneous correction.

{0013}

{Embodiments of the Invention} Desirable embodiments of the present invention are described in detail below in reference to the figures. Figure 1 is a schematic constitutional diagram used for schematically presenting the quality inspection method used during tube expansion of steel tubes pertaining to the present invention. A long tube 30 is shown in cross section. Said long tube 30 is a tube produced by welding relatively short steel tubes 30a, 30b, 30c... at weld regions 31a, 31b... In the figure, only three steel tubes are shown, but these tubes continue downwards.

{0014} The tube expansion mandrel 20 has a cylindrical part and a tapered part as shown in the figures, and a load P is applied from behind (upwards in the figure). As the mandrel travels forward (downwards in the figure), the interior wall of the long tube is pressed outwards in a radial direction due to the aforementioned tapered part, thus expanding the aforementioned long tube 30. The AE sensor 10 is situated in contact with the outer wall of the long tube, and the vibrations at said outer surface are converted into signals as the aforementioned tube expansion is taking place. Said signals are output to an inspection device main unit 100 to which it is connected.

{0015} Figure 2 is a control block diagram showing an example of the signal processing structure in the quality inspection device implemented in the present invention. In the quality inspection device main unit 100 shown in (a), the AE sensor 10 is connected to an absolute value processor 101, and the absolute value processor 101 is connected to a comparative processor 103. An aberration decision standard value setting part 102 is also connected with the comparative processor 103, and the comparative processor 103 is connected to a notification means 110.

{0016} The aforementioned absolute value processor 101 removes the direct current component of the output signal from the AE sensor 10, and outputs signals that have been converted into absolute values. The aforementioned aberration decision standard value setting part 102 is the part where the aberration decision standard value Th1 is set, which is the threshold value for determining the size of the signal amplitude from the AE sensor 10. The aberration decision standard value Th1 should be set at a value that is between the AE sensor signal amplitude when tube expansion is occurring without aberration, and the AE sensor signal amplitude when quality aberrations occur.

{0017} For example, the operator uses a standard value setting knob that is provided in order to set the aberration decision standard value obtained experimentally beforehand in accordance with the type of steel tube that is the subject of tube expansion. In this case, the value is automatically set to a value determined by multiplying the AE sensor signal amplitude  $A_s$  at time  $t_s$  in the initial stage in which the tube expansion process is initially occurring in said long tube 30 by a constant  $k_1$  that has been determined beforehand (where  $k_1 > 1$ ).

{0018} The aforementioned comparative processor 103 compares the signal input from the absolute value processor 101 with the aforementioned aberration decision standard value Th1, and when the signal from the absolute value processor 101 exceeds the aberration decision standard value Th1, a high-value generation signal is output. When the aforementioned high value generation signal is input into the notification means 110, a quality aberration is judged to have occurred, and an indication of this occurrence is sent to the operator by a tone or display.

{0019} In this manner, when quality inspection is to be carried out by the quality inspection device main unit 100 constituted in the manner shown in (a), the direct current component is taken from the signal from the AE sensor 10, and is rectified to obtain an amplitude. When the signal amplitude from

the AE sensor 10 exceeds the aberration decision standard value, a notification is made regarding the occurrence of aberration.

{0020} The quality inspection device unit 100 shown in (b), as can be seen from the figure, has a pulse counting processor 104 between the notification means 110 and the comparative processor 103 constituting the quality inspection device shown in (a) above. The pulse counting processor 104 is connected to the comparative processor 103 and the notification means 110. The number of the aforementioned high value generation signals received from the comparative processor 103 is calculated, and when this number reaches or surpasses the number that has been previously set, a quality aberration occurrence signal is output. In this case, a quality aberration occurrence signal is output when the number of occurrences of high value generation signals is 2 or greater.

{0021} Consequently, when quality inspection is carried out with a quality inspection device unit 100 constituted as indicated in (b), the signal from the AE sensor 10 is removed and rectified, and its amplitude is obtained. When the signal amplitude from the AE sensor 10 exceeds the aberration decision standard value two or more times, notification of an occurrence of quality aberration is made.

{0022} In addition, in this case, the pulse counting processor 104 transmits the number of high value generation signals to the notification means 110 in addition to the aforementioned quality aberration generation signal. The notification means 110 should be constituted in such a manner that notification is made regarding the occurrence of quality aberration, and the degree of quality aberration in accordance with the number of high value generation signals. For example, the device may be constituted so that the number of high value generations itself is made known, but in this case, notification indicating "slight" in regard to the degree of aberration is made when the number is 2 or 3, notification indicating "moderate" is made when the number is 4 or 5, and notification indicating "high" is made when the number is 6 or greater.

{0023} The quality inspection device unit 100 shown in (c) is expanded upon by adding a peak detector 107 to the quality inspection device presented in (a). Output from the absolute value processor 101 and output from the comparative processor 103 is input into the peak value detector 107, and this is linked to the notification means 110. When the aforementioned high value generation signal is output from the aforementioned comparative processor 103, the peak value detector 107 retains the peak value of the output of the absolute value processor 101 at this time, and outputs this value to the aforementioned notification means 110.

{0024} Thus, the notification means 110 reports the degree of quality aberration based on the aforementioned peak value in addition to reporting the occurrence of quality aberration. For example, the magnitude of the peak value itself may be reported, but in this case, notification of a "high", "moderate" or "low" determination is made in regard to the degree of aberration based on the magnitude of the peak value.

{0025} When quality inspection is carried out using the quality inspection device unit 100 constituted as indicated in (c), the signal from the AE sensor 10 is rectified after removing the direct current component, and the amplitude is obtained. When the signal amplitude of the AE sensor 10 exceeds the aberration decision standard value Th1, sound or display is used in order to present an indication of an occurrence of aberration and the degree of quality aberration based on the peak value of the AE sensor signal amplitude at the time of occurrence of said quality aberration.

{0026} The quality inspection device unit 100 shown in (d) is a unit in which an envelope detector 106 is also included between the absolute value processor 101 and the comparative processor 103 in the quality inspection device presented in (a), and a pulse width discriminator 108 is also provided between the comparative processor 103 and the notification means 110. The aforementioned envelope detector 106 outputs an envelope signal linking each of the maximum values of the output signals of the absolute value processor 101, and this is transmitted to the comparative processor 103. The comparative processor 103 outputs a high value generation signal to the notification means 110 when the output of the envelope detector 106 is larger than the aforementioned aberration decision standard value Th1. The pulse width discriminator 108 transmits an indication of an aberration occurrence and the length of time for the aforementioned high value generation to the notification means 110 when the time of the aforementioned high value generation signal is longer than a determined time period.

{0027} Thus, the notification means 110 performs notification of a quality aberration occurrence and degree of quality aberration based on the length of the aforementioned high value generation signal. For example, notification may be made as to the length of the aforementioned high value generation signal itself, but in this case, notification is made as to the results of determination based on "high", "moderate" or "low" in regard to the degree of aberration determined based on the length of the aforementioned high value generation signal period.

{0028} When quality inspection is carried out with the quality inspection device unit 100 constituted as shown in (d), the direct current component is removed from the AE sensor 100 signal, and the time for which the envelope intensity of the rectified signal exceeds the aberration decision standard value is calculated. If said time is longer than the determined time period, then sound or display is used in order to make a notification regarding quality aberration and the degree of quality aberration determined based on the time that the envelope intensity exceeded the aberration decision standard value TH1.

{0029} Figure 3 presents a schematic diagram in which the signal waveform for each of the processors is shown in common for Figure 2a, 2b and 2c. Specifically, Figure 3 shows the waveforms outputs at each part of the quality inspection device unit 100 when a quality aberration has occurred at the connection 31b during tube expansion, for the quality inspection system shown in Figure 1, whereas (a) shows the output signal for the AE sensor 10, (b) shows the output signal for the absolute value processor 101, and (c) shows the output value for the comparative processor 103.

{0030} The waveform shown in (a) will be described in sequence. When the tube expansion process is initiated with advancement of the tube expansion mandrel 20 at time  $t_0$ , vibrations are generated via acoustic emission (AE) arising due to plastic deformation, etc., occurring with tube expansion and vibrations are generated due to friction between the long tube 30 and the tube expansion mandrel 10 as advancement occurs (these vibrations are referred to in combination as "tube expansion vibrations"). When there is no aberration in quality, the tube expansion vibrations give a comparatively weak elastic wave. Consequently, for the period extending from time  $t_0$  to time  $t_1$  during tube expansion of the steel tube 30a, a signal waveform having a comparatively small amplitude is output by the AE sensor 10.

{0031} Next, during the period from time  $t_1$  to time  $t_2$  in which tube expansion of the weld 31a occurs, said weld region 31a has been welded by mechanical joining, diffusion welding or welding, so its hardness is higher than that of the steel tube 30a. As a result, the progress of the tube expansion mandrel 20 slows, and the aforementioned tube expansion vibrations give vibrations of even weaker amplitude. At this time, the AE sensor 10 outputs a signal waveform for vibrations that are smaller from time  $t_0$  to time  $t_1$ . During the time from  $t_2$  to  $t_3$  in which the steel tube 30b expands, the AE sensor 10 outputs a signal waveform with a comparatively weak amplitude as with the time period from time  $t_0$  to  $t_1$  described above.

{0032} When there is a crack generated during tube expansion of the connection 31b, the energy emanates from the crack, and an elastic wave with a comparatively large amplitude is produced. The tube expansion vibrations that include said elastic waves are detected by the AE sensor 10, and during the period from time  $t_3$  to time  $t_4$ , a signal waveform with a comparatively large amplitude is output. Subsequently, as shown in the figure, the AE sensor 10 outputs a signal waveform that has a comparatively small amplitude from time  $t_4$  to time  $t_5$  during tube expansion of the steel tube 31c as shown in the figure. Then a signal waveform with an even smaller amplitude is output from time  $t_5$  to time  $t_6$  during expansion of the next weld region thereof not shown in the figure.

{0033} Meanwhile, the output waveform from the absolute value processor 101 is the absolute value conversion determined after removing the direct current component of the AE sensor output shown in (a), thus producing the waveform shown in (b). In addition, the comparative processor 103 compares the output signal from the aforementioned absolute value processor 101 with the aberration decision standard value TH1 set as described above, and a "Hi" signal is output when the value is larger than said standard value TH1, whereas a "Lo" signal is output when said value is smaller than said standard value.

{0034} Consequently, when the output signal of the absolute value processor 101 shown in (b) is input, the comparative processor 103 outputs the waveform shown in (c). During the time from time  $t_0$

to time  $t_3$ , the output remains "Lo" because there is no input from the absolute value processor 101 that is higher than the aforementioned aberration decision standard value TH1. Next, because a crack is generated in the time period from time  $t_3$  to  $t_4$ , a signal having an amplitude that is larger than the aforementioned aberration decision standard value TH1, as shown in (b) is input, and pulses P1 to P3 are output during the time period from time  $t_3$  to  $t_4$  in (c). Subsequently, there is no output that is larger than the aforementioned standard value TH1 during the time period from time  $t_4$  to  $t_6$ , and so the value remains "Lo".

{0035} With the respective quality inspection device units 100 having the constitutions described in (a)-(c) of Figure 2, the following types of processes are carried out based on the output signals shown in (a)-(c) of Figure 3. With the quality inspection device unit 100 shown in Figure 2(a), a "Hi" pulse is output from the comparative processor 103, and an aberration generation signal is output to the notification device 110, so that notification of an occurrence of an aberration is made by the notification means 110.

{0036} With the quality inspection device unit 100 shown in Figure 2(b), the number of pulses output from the comparative processor 103 is 3, and because this corresponds to 2 or more occurrences, notification is made regarding an indication of quality aberration. In addition, notification is also made regarding the degree of quality aberration corresponding to a pulse number of three for the high value signals.

{0037} In the quality inspection device unit 100 shown in Figure 2(c), the peak value detector 107 produces three outputs of "Hi" signals from the comparative processor 103, and so peak values PK1 through PK3 of the absolute value processor 101 output are detected during the pulse generation time. Consequently, an aberration occurrence signal and signals representing the peak values PK1 to PK3 are sent to the notification means 110. The notification means 110 then makes notification, via sound or display, of the occurrence of quality aberration, and the degree of the quality aberration corresponding to the aforementioned peak values PK1 through PK3.

{0038} Figure 4 is a diagram that presents a schematic representation of the signal waveforms for each of the processors in Figure 2(d). Figure 4, specifically, represents the waveform output at each of the parts of the quality inspection device unit 100 when there is a quality aberration at the connection 31b during tube expansion carried out by the quality inspection system presented in Figure 1, whereas (a) represents the output signal of the AE sensor 10, where this waveform is similar to that of Figure 3(a). Here, (b) represents the output signal of the absolute value processor 101, where this waveform is similar to that of Figure 3(b), and (c) represents the output waveform of the envelope detector 106.

{0039} The quality inspection device unit 100 having the constitution of (d) in Figure 2 detects quality aberration in the following manner based on the signals presented in Figure 4. The variation in envelope intensity is determined by the pulse width determination part 108 and the comparative processor 103, and when the time during which said envelope intensity is greater than the aforementioned aberration decision standard value Th1 (time over which the comparative processor 103 outputs the aforementioned high value generation signal; represented by T in the figure) is longer than the predetermined time, an aberration generation signal and a signal that transmits the aforementioned time T is sent to the notification means 110. The notification means 110 then makes a notification, via sound or display, as to the occurrence of quality aberration, and the degree of quality aberration corresponding to the aforementioned time period T.

{0040} Figure 5 is a control block diagram showing a processing system example that is different from the steel tube quality inspection device presented in Figures 2(a)-(d). The AE sensor 10 is attached to the aforementioned long tube 30, and surface vibrations from the long tube 30 are converted to signals that are output. The absolute value processor 101 removes the direct current component of the AE sensor 10 output signal, and outputs the absolute value of the resulting signal to the amplification processor 105 and envelope detector 106.

{0041} The amplification processor 105 is the part that amplifies the absolute value processor 101 output, and in order to correct for attenuation of the elastic waves reaching the AE sensor at this time, said level of amplification is made such that it is inversely proportional to said envelope intensity at any give time t, based on the output of the envelope detector 106. Consequently, the level of

amplification at inspection time  $t_s$  is set at  $A_s/A_t$  using, as reference, the intensity  $A_s$  of the envelope at time  $t_s$  during the initial tube expansion period.

{0042} The envelope detector 106 outputs a signal produced by carrying out specified processing on the envelope that links each maximum of the output signals from the absolute value processor 101, and this signal is transmitted to the amplification processor 105. As described in detail below, when no aberrations are being generated during tube expansion of the main steel tube bodies 30a, 30b, 30c..., the envelope is processed taking the amplitude of the AE sensor output as an index of the aforementioned amplification level correction. The result is output to the amplification processor 105.

{0043} The aberration decision standard value setting part 102 is the part whereby the aberration decision standard value  $Th2$  is set, which is the threshold value for determining the magnitude of the output signal amplitudes from the amplification processor 105. The aberration decision standard value setting part 102 automatically is set to a value found by multiplying the amplitude  $A_s$  of the output from the envelope detector 106 at time  $t_s$  during the initial period of the tube expansion process of said long tube 30 by a predetermined constant  $k_2$  (where  $k_2 > 1$ ).

{0044} The aforementioned comparative processor 103 compares the signal input from the amplification processor 105 with the aforementioned aberration decision standard value  $Th2$ , and outputs a high value generation signal when the signal of the amplification processor 105 is greater than the aberration decision standard value  $Th2$ . The notification means 110 notifies the operator via sound or display as to the occurrence of quality aberration when the aforementioned high value generation signal has been input.

{0045} Figure 6 and Figure 7 are waveform diagrams that give a schematic presentation of the outputs of each of the constitutive processors shown in Figure 5. Specifically, the figures are output waveform diagrams for each of the constitutive processors shown in Figure 5 when cracks occur in the connection 32b along with tube expansion of a long tube 30 having the constitution shown in Figure 1.

{0046} The signal shown in Figure 6(a) is produced by conversion of the vibrations from the long tube into signals by the AE sensor 10. This waveform is the same as the waveform shown in Figure 3(a) and varies similarly. Specifically, an amplitude signal that is comparatively small is output from time  $t_0$  to time  $t_1$  as tube expansion of the steel tube 30a is occurring, whereas an amplitude signal waveform that is smaller than the waveform from time  $t_0$  to time  $t_1$  is output over the time period from time  $t_1$  to time  $t_2$  during which tube expansion of the weld region 31a occurs.

{0047} Subsequently, over the time period from time  $t_2$  to time  $t_3$  during which tube expansion of the steel tube 30b occurs, the AE sensor 10 outputs a signal waveform with an amplitude that is comparatively weak, as with the waveform output over the time period from  $t_0$  to  $t_1$  above. During the period from time  $t_3$  to  $t_4$  during which cracking occurs during tube expansion in the connection 31b, a signal waveform with a comparatively large amplitude is output. Subsequently, a signal waveform with a comparatively small amplitude is output over the period from time  $t_4$  to  $t_5$  during which tube expansion of the tube 30c occurs. A signal waveform with a small amplitude is again output over the time period from time  $t_5$  to  $t_6$  during which the subsequent weld region is undergoing tube expansion (not shown in the figure).

{0048} The waveform shown in Figure 6(b) is the output signal from the absolute value processor 101, and results from removing the direct current component of the output signal from the AE sensor 10, and performing absolute value conversion. The waveform represented by the solid line in Figure 6(c) is the output signal from the envelope detector 106, and is produced as a result of processing the envelope from the outputs of the absolute value processor 101 in the manner described below.

{0049} Specifically, the periods from time  $t_1$  to time  $t_2$ , time  $t_3$  to time  $t_4$ , and time  $t_5$  to time  $t_6$ , are times when tube expansion is occurring in weld regions 31a, 31b, 31c... of the long tube, or times when aberrations are occurring. The envelopes for these times produce the waveforms represented by the broken lines in Figure 6(c), but the waveforms represented by said broken lines are not output in these time periods. Rather, values interpolated from the change in envelope intensity at a time before, after, or before and after (represented by the solid lines in the figure) are output as the envelope intensity  $A_t$  for said time points.

{0050} For example, when the difference or ratio of the actual calculated value and the predicted value determined from the change in the envelope using the aforementioned standard exceeds a predetermined range, said predicted value is used instead of said actual value. Thus, the envelope intensities during tube expansion in the weld regions and during quality aberration will be far outside the values predicted from the transition of the envelope intensity during tube expansion of the main body of the steel tube, and so the aforementioned predicted values are used instead of the envelope intensity at these times.

{0051} Figure 7(a) shows the output signal from the amplification processor 105. With regard to the output, the amplification processor 105 amplifies the signal shown in Figure 6(b) that is output by the absolute value processor 101 by a degree of amplification that is inversely proportional to the intensity of the envelope detector output represented by the solid line in Figure 6(c) in order to correct for damping of the elastic waves reaching the AE sensor. As is seen in the figure, the degree of amplification of the signal from the absolute value processor 101 is increased by the amplification processor 105 in accordance with the distance of the AE sensor from the site of tube expansion. An output is thus made after correcting for damping of the elastic waves produced by tube expansion.

{0052} Figure 7(b) shows the output signal from the comparative processor 103. The comparative processor 103 outputs a "Hi" signal when the output of the amplification processor exceeds the aforementioned aberration decision standard value  $Th_2$ , and thus outputs pulse signals P1 to P3 which are high value generation signals during the period from time  $t_3$  to  $t_4$ . The notification means 110 receives said high value generation signals, and uses sound or display to make a notification as to the occurrence of quality aberration.

{0053} In addition, a pulse counting processor is provided between the aforementioned comparative circuit part 103 [sic] and the aforementioned notification means 110, whereby the number of the aforementioned high value generation signals from the comparative processor 103 is counted. This number is then transmitted to the notification means 110. The notification means 110, thus renders notification regarding the occurrence of quality aberration and the degree of quality aberration based on the number of the high value generation signals.

{0054} Meanwhile, a peak value detector is provided that detects the maximum value for the amplification circuit output immediately after the point when the high value generation signal is output from the aforementioned comparative circuit 103. The notification means 110 thus renders notification as to the occurrence of quality aberration, and the degree of quality aberration based on the magnitude of said peak value.

{0055} Figure 8 is an output waveform diagram for each of the processors when cracking occurs during actual tube expansion of the steel tube. Specifically, the figure is an output waveform diagram when quality inspection is actually being carried out according to the present invention using the configuration described in Figure 1 and Figure 2(a). In (a), the high-amplitude output waveforms occurring approximately at times  $t_1$ ,  $t_2$  and  $t_3$  are generated due to the occurrence of cracking at these time points.

{0056} As is clear from the figures, when the aforementioned aberration decision standard value  $Th_1$  is set to  $5x$  the value of the amplitude  $As$  of the AE sensor at time  $t_s$  in the initial period of tube expansion using the aforementioned aberration decision standard value setting part 102, the comparative processor 103, as shown in (b) generates pulse signals which are the aforementioned high value generation signals, the first being close to time  $t_1$ , the second being close to time  $t_2$  and the third being close to time  $t_3$ . Consequently, the notification means sends notification of aberration occurrences at these time points  $t_1$ ,  $t_2$  and  $t_3$ .

{0057} The present invention is not restricted by the embodiments described above, and various modifications are possible within a range that does not exceed the scope of the invention. For example, it goes without saying that the steel tube that is the subject of inspection is not restricted to one that has weld regions. The site of attachment of the AE sensor is also not restricted to the side surface of the tube, as the sensor may be attached at the end surface. In the embodiments described above, the tube expansion mandrel had a tapered region, but mandrels are not restricted to this type. For example, a tube expansion mandrel can be used that has expanding diameter rollers present on the

outer surface of the mandrel, so that the internal wall of the steel tube is pressed outwards in a radial direction by means of said expanding diameter rollers.

{0058} On the other hand, regarding setting of the aforementioned aberration decision standard value, modes are not restricted to the process represented in the embodiment, and the value may be set to a value that is between the amplitude of the signal determined when normal tube expansion is occurring and the amplitude of the signal determined when quality aberration occurs. In addition, in the aforementioned embodiment, processing performed by analog signal processors can be carried out by means of digital signal processing. For example, an A/D converter can be provided after the absolute value processor 101 or the amplification processor 105 so that their outputs are converted to digital signals, which are then subjected to digital signal processing for subsequent processes.

{0059}

{Effects of the Invention} By means of the quality inspection method used during tube expansion described in Claim 1 of the present invention, as tube expansion occurs with movement of the tube expansion mandrel, vibrations are generated at the site of tube expansion. When quality aberrations are generated in the steel tube, the AE sensor signal amplitude increases relative to the amplitude at previous and subsequent time points. By employing this increase, the invention has the merit of allowing determination regarding an occurrence of quality aberration as tube expansion occurs without installing special irradiation devices or drive devices for quality inspection.

{0060} In addition, vibrations generated by tube expansion and by movement of the tube expansion device are transmitted through the steel tube to an AE sensor that is at a location distant from the site where tube expansion is occurring, so that it is possible to perform quality inspection during tube expansion with the inspection device itself fixed at a specific location. In addition, there is also the merit that quality inspection can be carried out as the long steel tube is undergoing expansion. Because the rate of transmission of said vibrations is extremely fast, when quality aberrations such as cracking occur during tube expansion, it is possible to detect the occurrence of quality aberration and the degree of quality aberration nearly simultaneous to its occurrence.

{0061} Moreover, with the quality inspection method used during tube expansion described in Claim 2, in addition to the merits of the quality inspection method described in Claim 1, there is the merit that the degree of quality aberration can be determined simultaneous to the quality aberration with the inspection device itself fixed at a determined location, without requiring the use of special drive devices or irradiation devices for quality inspection.

{0062} Moreover, with the quality inspection method used during tube expansion described in Claim 3, the degree of amplification of the AE sensor is increased in accordance with a continual decrease in AE sensor signal amplitude, or the degree of amplification of the AE sensor signal is decreased in accordance with a continual increase in AE sensor amplitude. By this means, damping of the elastic waves generated due to tube expansion occurring during the time it takes them to reach the AE sensor can be compensated for with high precision, so that it is possible to increase the reliability and accuracy of processing carried out using said AE sensor signal.

{0063} For example, as the tube expansion mandrel becomes increasingly distant from the AE sensor, the decrease in AE sensor signal is compensated for, and thus even with long steel tubes, it is possible to determine the occurrence of quality aberration and the degree of quality aberration with a high level of accuracy. Moreover, because stable determination of the occurrence of quality aberration and the degree of quality aberration is possible with little fluctuation in AE sensor signal amplitude due to change in transmission distance, a quality inspection method for use during tube expansion is provided that increases the reliability of these determinations.

{Brief Description of the Figures}

{Figure 1} Schematic constitutional diagram that presents a summary of the quality inspection method during tube expansion of steel tubes pertaining to the present invention.

{Figure 2} Control block diagram showing an example of the signal processing system for the steel tube quality inspection device used in the present invention.

{Figure 3} Diagram giving a schematic presentation of the signal waveforms for each of the processors of Figure 2(a), (b) and (c), where (a) is the waveform diagram of the output signal from the

AE sensor, (b) is the waveform diagram of the output signal from the absolute value processor and (c) is the waveform diagram of the output signal from the comparative processor.

{Figure 4} Diagram giving a schematic presentation of the signal waveforms for each of the processors for Figure 2(d), where (a) is the waveform diagram of the output signal from the AE sensor, (b) is the waveform diagram of the output signal from the absolute value processor and (c) is the waveform diagram of the output signal from the envelope detector.

{Figure 5} Control block diagram showing an example of a processing system other than that of the steel tube quality inspection device presented in Figure 2(a)-(d).

{Figure 6} Waveform diagrams giving a schematic presentation of the outputs of the constitutive processors for the steel tube quality inspection device shown in Figure 5, where (a) is the waveform diagram of the output signal from the AE sensor, (b) is the waveform diagram of the output signal from the absolute value processor and (c) is the waveform diagram of the output signal from the envelope detector.

{Figure 7} Waveform diagrams giving a schematic presentation of the outputs of the constitutive processors for the steel tube quality inspection device shown in Figure 5, where (a) is the waveform diagram of the output signal from the amplification processor and (b) is the waveform diagram of the output signal from the comparative processor.

{Figure 8} Waveform diagrams for the various processors when cracking occurs during actual tube expansion of a steel tube, where (a) is the output waveform diagram from the absolute value processor amplification processor and (b) is the output waveform diagram from the comparative processor.

{Key}

- 10 AE sensor
- 20 Tube expansion mandrel
- 30 Long tube
- 30a, 30b, 30c... Steel tubes
- 31a, 31b... Weld regions
- 100 Quality inspection device unit
- 101 Absolute value processor
- 102 Aberration decision standard value setting part
- 103 Comparative processor
- 104 Pulse calculator
- 105 Amplification processor
- 106 Envelope detector
- 107 Peak value detector
- 108 Pulse width determination part
- 110 Notification means

[see source for figures]

Figure 1.

Figure 3

(a)

AE sensor output

Time

(b)

Absolute value processor output

Time

(c)

Comparative processor output

Time

Figure 5  
[see Key above]

Figure 2  
[see Key above]

Figure 4  
(a)  
AE sensor output  
Time  
(b)  
Absolute value processor output  
Time  
(c)  
Envelope detector output  
Time

Figure 6  
(a)  
AE sensor output  
Time  
(b)  
Absolute value processor output  
Time  
(c)  
Envelope detector output  
Time

Figure 7  
(a)  
Amplification processor output  
Time  
(b)  
Comparative processor output  
Time

Figure 8  
(a)  
Comparative value processor output  
Time  
(b)  
Comparative processor output  
Time

Continued from the front page

F Terms (Reference)      [see source for codes]



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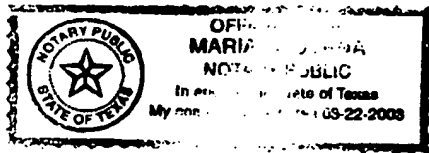
  
Kim Stewart

TransPerfect Translations, Inc.  
3600 One Houston Center  
1221 McKinney  
Houston, TX 77010

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